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CONTRIBUTION OF GLACIER MELT WATER TO THE FLOW OF THE BOW RIVER

PHASE I Part D

Compilation of data
and analysis of trends to the present

Final report

by

G J Young,
Wilfrid Laurier University

to

Government of the Province of Alberta
Department of Environmental Protection

June 1995

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Acknowledgements

I am particularly indebted to Corinne Schuster, Rob South and Al Wallace for all their efforts in support of this work during the past year. Without their dedication to the project the compilation and illustration of the data sources would not have been possible.

Gordon J Young

Executive Summary

Within the Bow River Basin, Alberta, the demand for water is rising. Already, especially at critical times of the year (late summer) and in years of low flows, demands exceed Alberta's entitlements to water.

Very important questions to be answered at a time when demand is outstripping supply are:

- to what extent is the supply variable over years and decades;
- whether there are long term trends in climate leading to changing stream flows;
- to what extent supplies can be relied upon in the future.

The water supply is derived primarily from the mountain regions in the upper catchment areas where precipitation is relatively high. Much of the mountain precipitation is stored seasonally as snowpacks and over periods of decades and centuries in the form of glaciers. Glaciers provide meltwater primarily in late summer and, in years with relatively low precipitation, glaciers compensate for low flows through additional melting. ***Thus glaciers play a crucial role in water supply for it is precisely when demand is highest that they give their most valuable contributions.***

Over the last few decades glaciers have been in recession, releasing water into the rivers in addition to the annual water budget. This process may well continue and for a number of years there may be a very welcome augmentation of flows. However, as glacier tongues recede to ever higher (and colder) elevations, the contributions of glacier melt to streamflow must, of necessity diminish. ***It is crucial to the assessment of the available future water resources to understand the quantities and timing of release of glacier ice from long term storage and the rate at which that component of the water supply is likely to change in magnitude.***

It is important to note that the significance of the diminution of glacier extent, with concomitant reduction in water supply, might be completely overshadowed by long term trends in climate, resulting in changes in precipitation quantities or timing of melt periods, or by shorter term but highly significant variations in climate such as a series of years influenced by El Niño events.

While there is a great deal of uncertainty regarding climatic variation over both short and long term time scales, it is possible (at least approximately) to quantify the volume of ice being released from storage over periods of decades and thus to identify the significance of this component of streamflow.

It is the purpose of this research to identify the contribution of glacier ice melt to streamflow, and the changes in that component of the water balance through time in the past and into the future. The geographic extent of the analyses is confined to the catchment of the Bow River above Banff, a catchment within which there has been minimal human influence.

To address the problem the research has been broken down into three phases, the first of which, "Compilation of data and analysis of trends to the present", is the subject of this Report.

Several types of data have been compiled, inspected for quality and consistency and are presented in summary, primarily in graphical form. The data bases include:

- A series of maps using a Geographical Information System (Terrasoft) to delineate basin and sub-basin boundaries; streams and lakes; elevation; forest cover; glacier extent; and bare rock areas. By overlaying basin boundaries, terrain types and elevation, hypsographic curves may be derived; these will be an integral component in the further analysis and interpretation of the streamflow records.

- The streamflow records of the Bow River above Banff and some records of nearby catchments which will be used in subsequent analyses.

- Selected meteorological records (not including those of questionable accuracy and consistency), snowcourse records and records of glacier mass balance.

Analyses to be undertaken in further phases of the research include:

- Utilizing analyses already undertaken in the adjacent Mistaya Basin, transpose changes in glacier extent since 1966 and transpose the discharge records to the highly glacierized sections of the upper Bow River Basin.

- From maps, aerial photography and (perhaps) from satellite imagery, reconstruct the extent of glaciers in the Bow Basin in the time period 1966 to present and calculate volumetric change.

- Calculate the effects of volumetric change of glaciers on the hydrographs for the whole Bow Basin above Banff and on its sub-catchments.

- Construct future scenarios with smaller glaciers and with different combinations of climatic inputs in order to understand likely water supply conditions in the future.

CHAPTER 1 Database I: Maps of the Bow River Basin above Banff and information contained in the Geographical Information System

This chapter describes the layout of the Bow River Basin above Banff. The basin covers some 2210 km^2 and ranges in elevation from 4500 to 11500 ft asl. Fig. 1.1 shows the layout of the basin with eight smaller sub-basins which have either active or inactive stream gauging stations. The drainage network with gauge sites is shown in fig. 1.2. The relief within the basin is shown in fig 1.3 and the distributions of forest and glacier cover are shown in figs. 1.4 and 1.5. A schematic of the relative positions of the stream gauge network within the major drainage network is shown in fig. 1.6.

A GIS (Terrasoft) has been employed in order to describe basin characteristics and as a basis for further analysis of the data. The superimposition of ***basin and sub-basin boundaries***, the ***relief information*** (derived from digitizing contour lines at 500ft intervals), and the ***land surface types*** (forest, glaciers, lakes and bare rock) allow hypsographic curves for the basins and sub-basins to be derived, illustrated in fig. 1.7. Table 1.1 provides a summary of the areal breakdown of land surface types within sub-basins. It is worth noting that within the basin as a whole there is only some 73 km^2 glacier cover (as calculated from 1950 maps) or 3.3% of the land area. More than half of this glacier area lies within the Lake Louise sub-basin. Table 1.1 also includes data from the adjacent Mistaya basin as the Mistaya has excellent stream gauging records and, because it is very similar in characteristics to the Hector Lake sub-basin, it will be used in later analyses for comparative study.

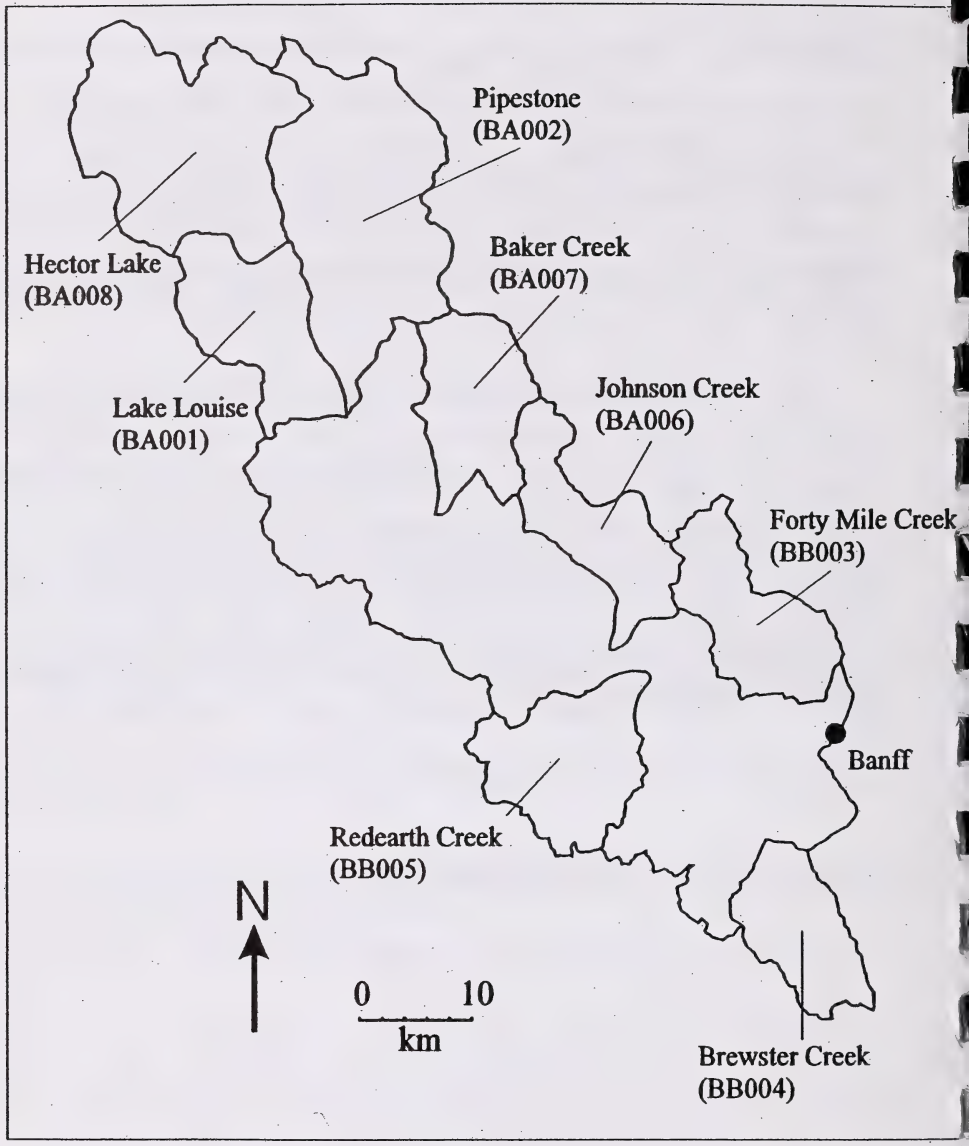


Fig. 1.1 The Bow River Basin above the Banff stream gauge (BB001), covering 2210 km^2, with sub-basins delineated.

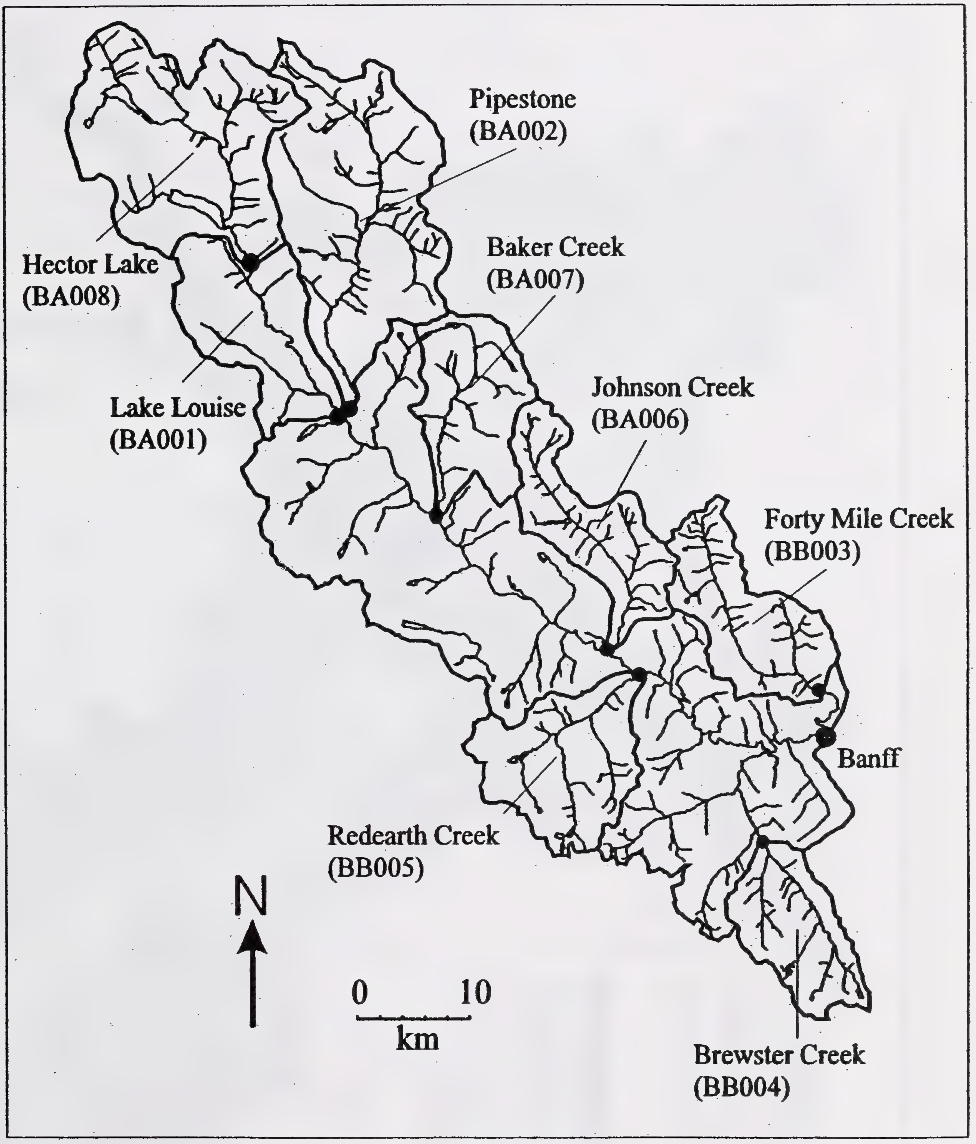


Fig. 1.2 The Bow River Basin above the Banff showing major drainage network and gauge sites for sub-basins.

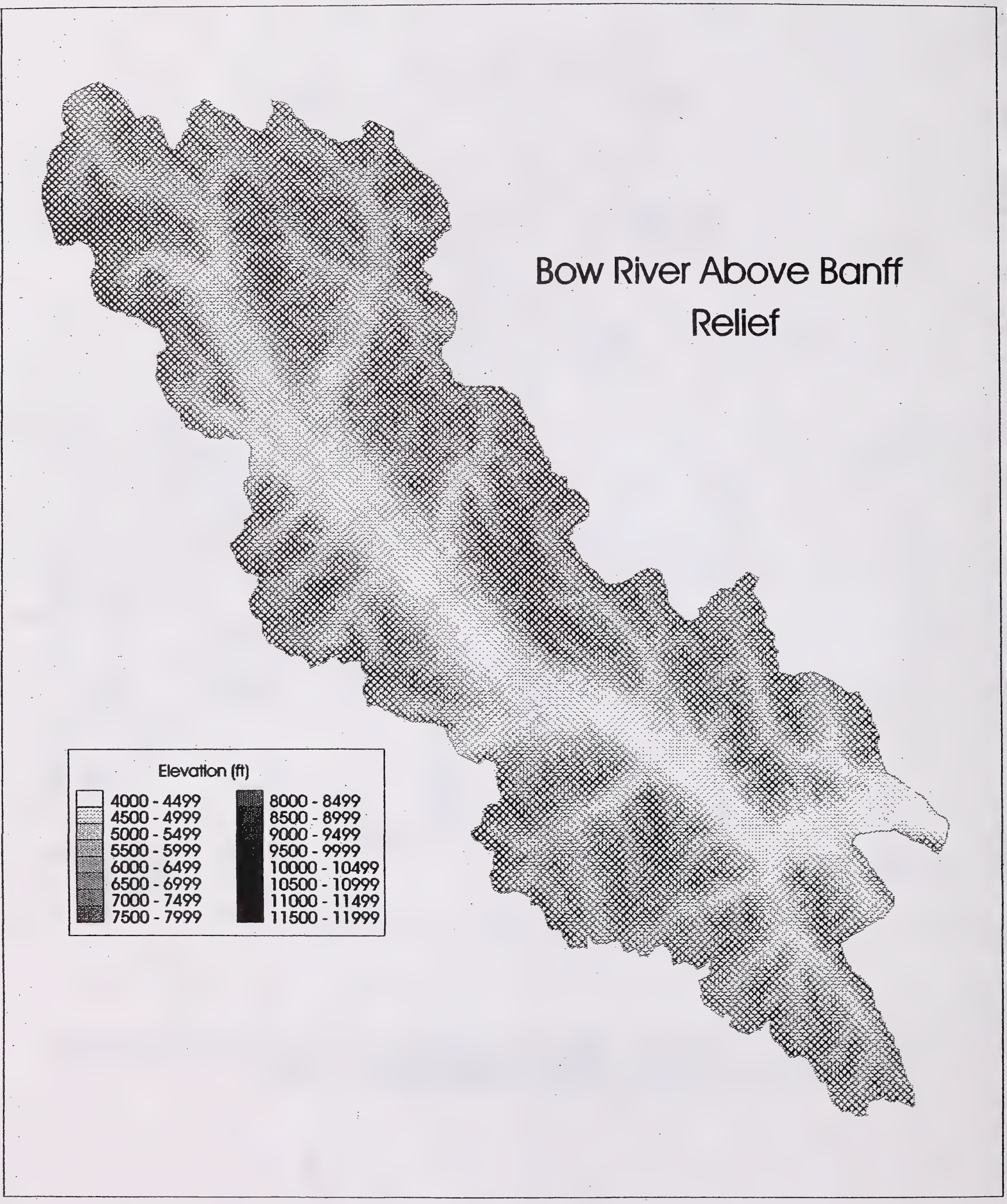


Fig. 1.3 Relief within the Bow River Basin above the Banff.

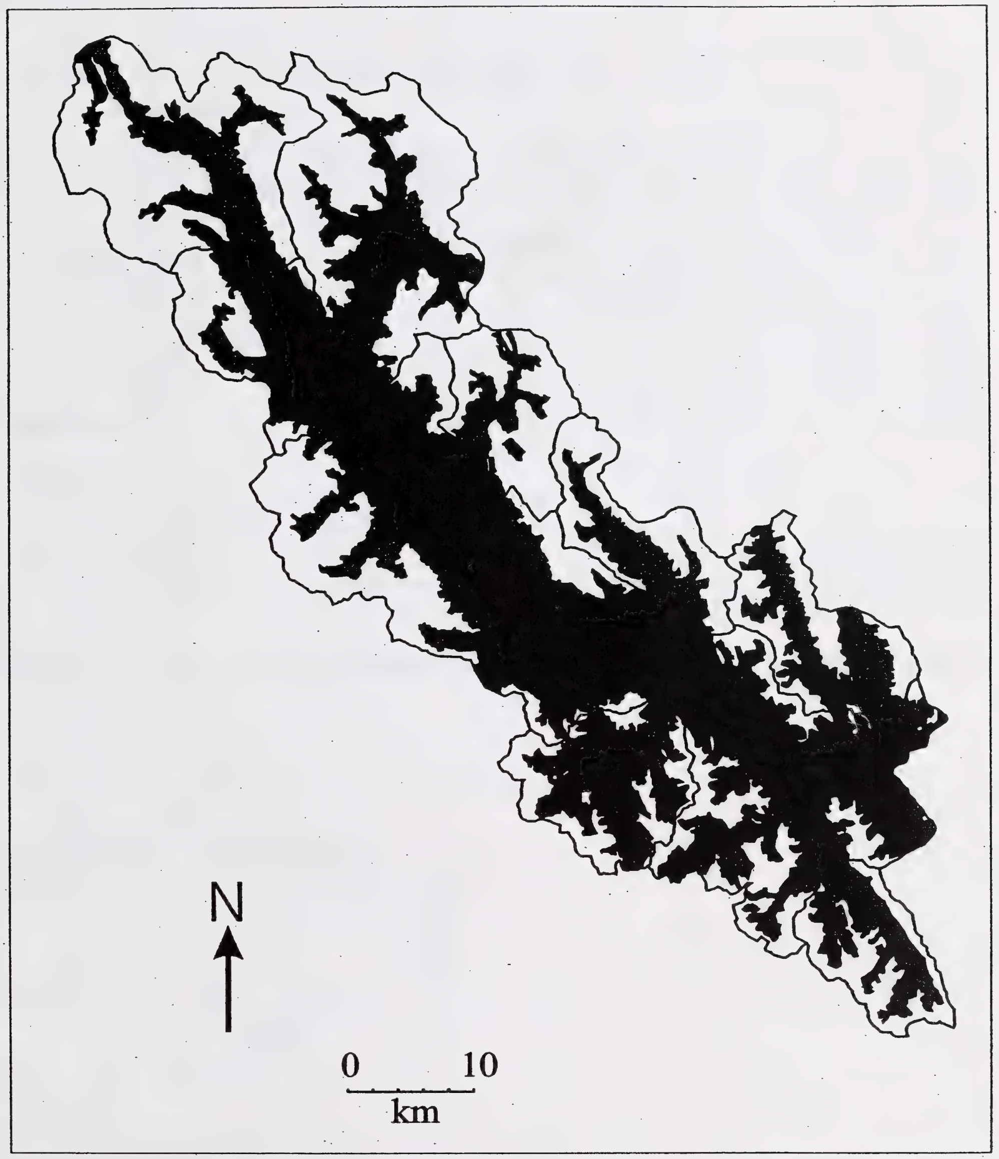


Fig. 1.4 Forest distribution within the Bow River Basin above the Banff.

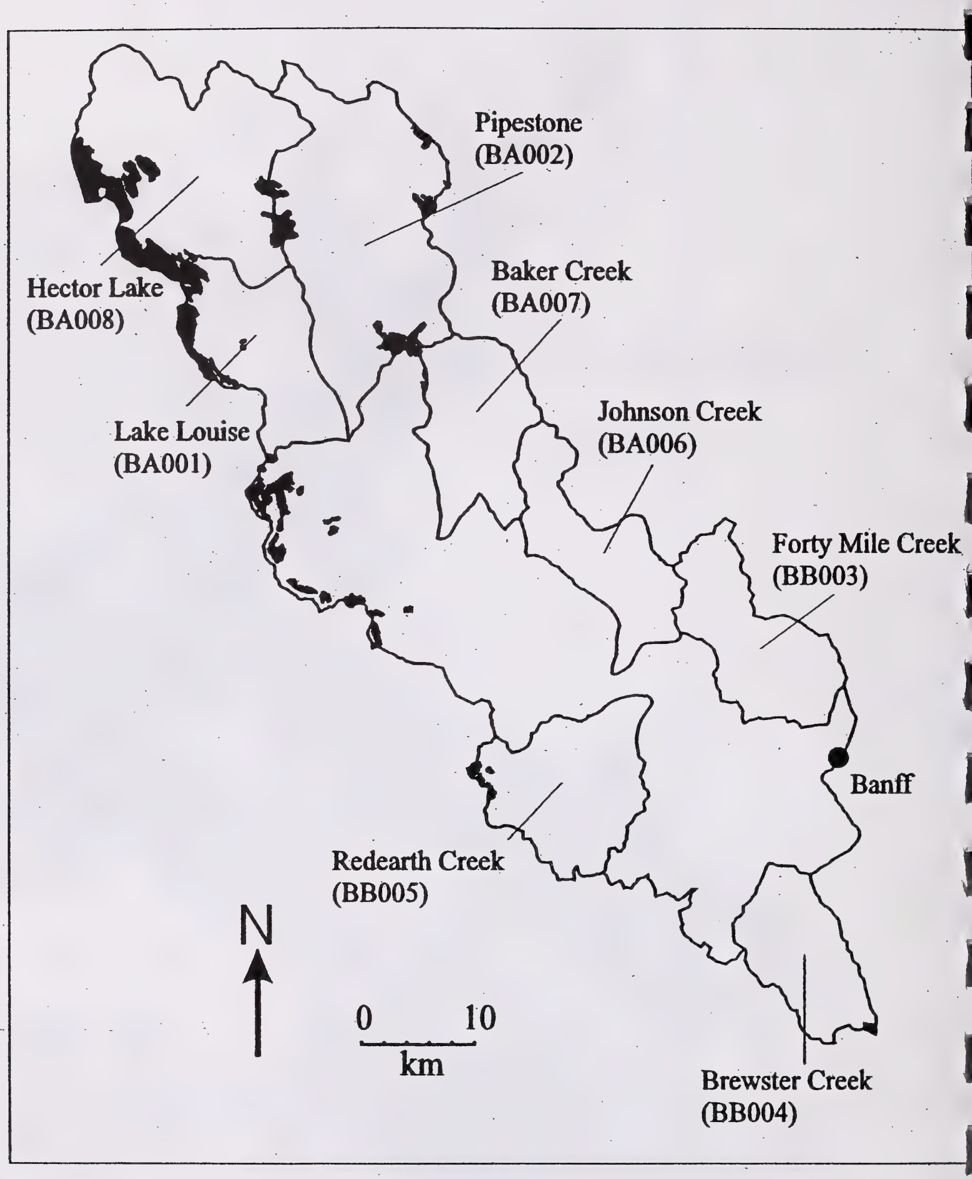


Fig. 1.5 Glacier distribution within the Bow River Basin above the Banff.

BASIN		Total Area	Forest	Glacier	Lake	Rock	%	%	%	%
		km. sq.					Forest	Glacier	Lake	Rock
Bow River at Banff	BB001	2226.66	1160.06	72.86	15.06	978.68	52.10	**3.27**	0.68	43.95
Lake Louise	BA001	425.55	174.78	45.13	9.04	196.60	41.07	**10.61**	2.12	46.20
Pipestone River	BA002	307.79	119.71	9.79	0.35	177.94	38.89	**3.18**	0.11	57.81
Johnson Creek	BA006	124.17	50.94	0.00	0.31	72.92	41.02	**0.00**	0.25	58.73
Baker Creek	BA007	125.49	40.34	0.09	0.59	84.47	32.15	**0.07**	0.47	67.31
Hector Lake	BA008	281.41	83.81	33.20	9.04	155.36	29.78	**11.80**	3.21	55.21
Forty Mile Creek	BB003	133.41	64.95	0.00	0.13	68.33	48.68	**0.00**	0.10	51.22
Brewster Creek	BB004	107.15	48.73	0.49	0.25	57.68	45.48	**0.46**	0.23	53.83
Redearth Creek	BB005	154.16	94.12	1.71	1.23	57.10	61.05	**1.11**	0.80	37.04
Rest of basin		848.97	566.48	15.65	3.18	263.66	66.73	**1.84**	0.37	31.06
COMPARATIVE BASINS										
Mistaya	DA007	247.21	83.81	26.63	5.84	130.94	33.90	**10.80**	2.40	52.90
Silverhorn Creek	DA010	19.99	1.91	0.58	0.00	17.50	9.60	**2.90**	0.00	87.50
Peyto Creek	DA008	22.25	0.00	12.12	0.00	10.13	0.00	**54.50**	0.00	45.50

Table 1.1 Characteristics of Bow River Basin above Banff and adjacent basins for comparative studies

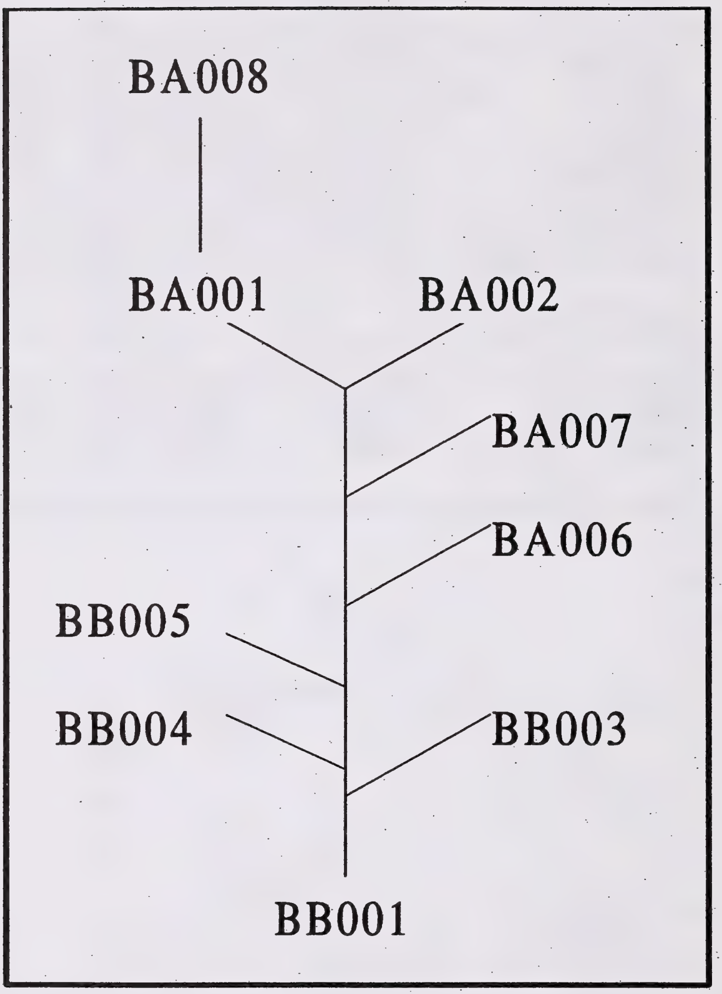


Fig 1.6 Schematic of relative positions of stream gauges within the Bow River Basin above Banff

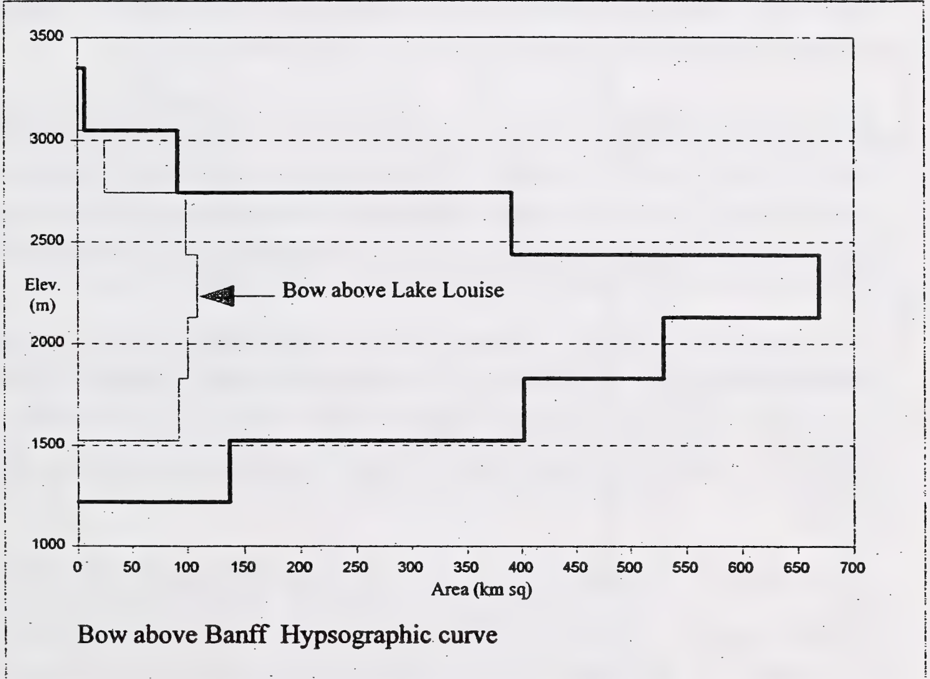


Fig. 1.7 Hypsographic curves for the basin of the Bow River above Banff and for the Bow River above Lake Louise

CHAPTER 2 Database II: Streamflow records

A summary of the streamflow records for the Bow River at Banff (BB001) and for 8 sub-basins (BA001,2,6,7,8, BB003,4,5) are presented in this chapter. Fig. 2.1 provides a Time line for the streamflow records for the Bow River above Banff and for gauges within the Mistaya basin contiguous to and immediately north of the Bow basin.

The overall flow record is summarised in fig. 2.2. It is apparent from this figure that there are no very obvious major trends in the 82 period of record. It is clear, however, that there have been extended periods of generally lower than average flows (the 1940s and the last two decades) and periods of generally higher than average flows (the 1960s). Fig. 2.3 further illustrates the discharge records by showing mean monthly flows. Differences in the hydrographs from year to year are apparent and the considerable contribution of the Lake Louise sub-basin is seen in fig 2.4. A further illustration of the dominance of the snowmelt phase in early summer is shown in fig. 2.5.

It will be noted from fig. 2.1 that, fortunately, for the period 1973-76 stream gauging was undertaken at all gauges. This will allow an intercomparison of the records for that time period. Fig. 2.6 shows mean monthly flows at Banff for the 1973-76 period compared to the mean monthly flows for the 82-year period of record. It shows that (again fortunately) within the 4-year 1973-76 record there were higher than average and lower than average years. The hydrographs in this 4-year period showed considerable diversity, as show by the daily records of the Bow River at Banff in fig. 2.7.

To illustrate the differences between sub-basins with different land cover characteristics fig. 2.8 presents mean monthly discharges 1973-76 for the Bow River at Banff, the Bow River below Hector Lake (almost 12% glacier covered) and the Forty Mile Creek (no glacier cover). The data are standardized to eliminate the effect of different areas within the basins. It is apparent that the Hector Lake gauge records high specific yields and that the maximum discharges are delayed until later in the summer.

A data base of discharges within each sub-basin has been linked to the GIS. This allows a mapped description of the relative contributions of sub-basins to overall basin yields. As illustration of this powerful technique, maps of sub-basin yield by month for June to September 1973-76 are presented in the Appendix. The yields have been standardised, ie yields have been expressed as $m^3 s^{-1} km^{-2}$, allowing ready intercomparison of sub-basin yields. This technique could also be applied on a daily or annual basis and will form the basis of future modelling programs.

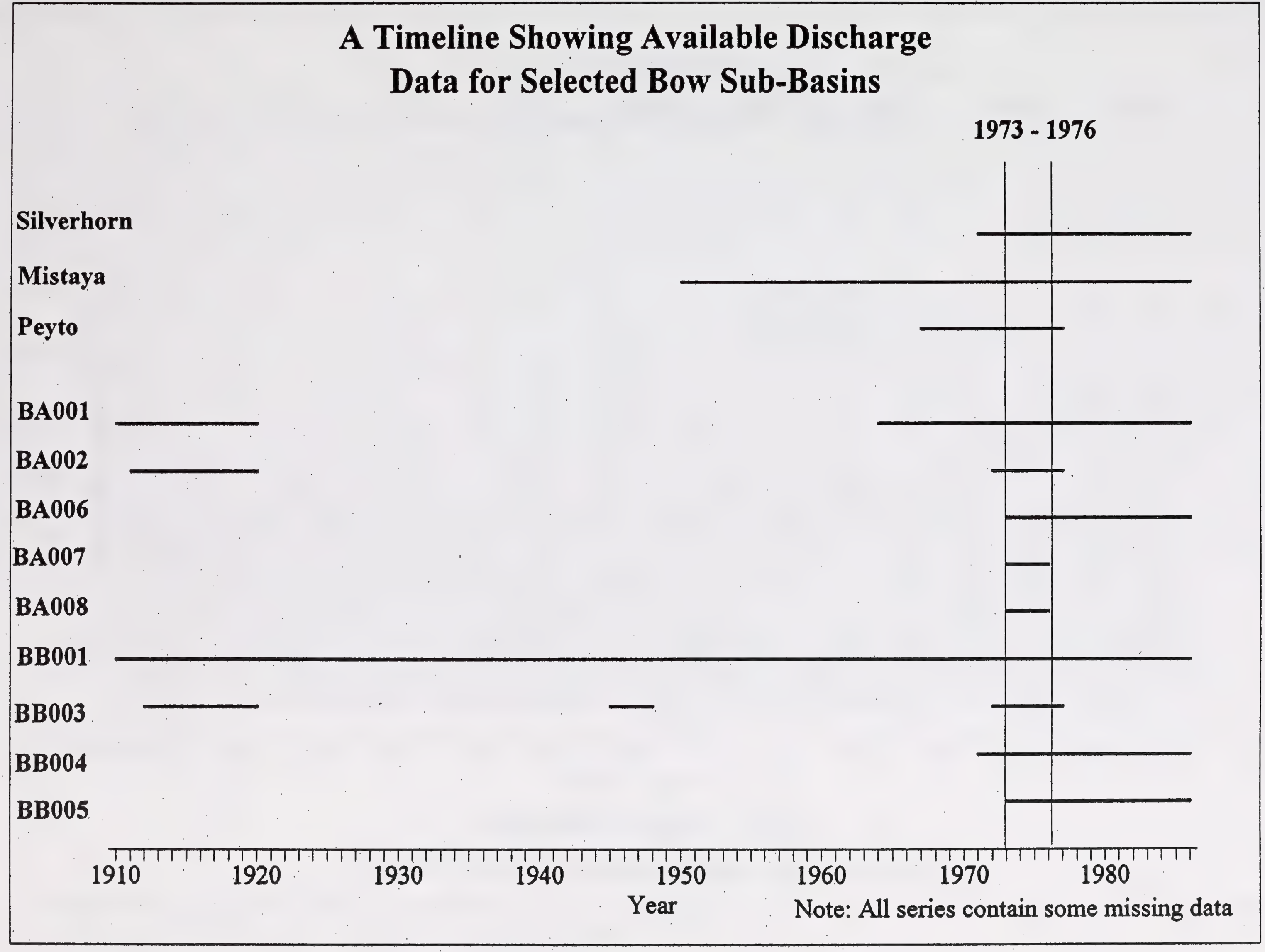


Fig 2.1 Time line of availability of major series of discharge within the Bow River basin above Banff and in the adjacent Mistaya Basin

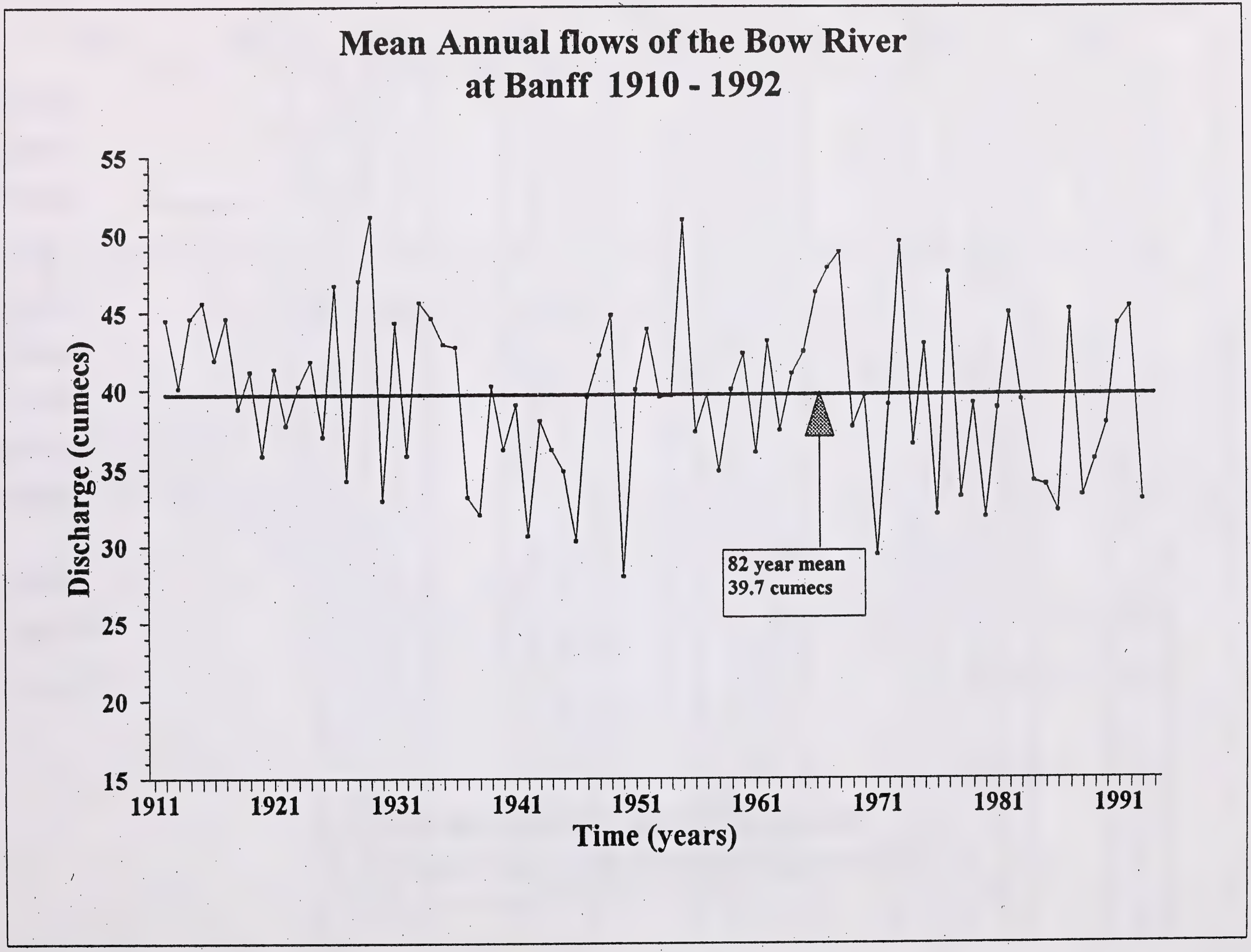


Fig. 2.2 Mean annual flows of the Bow river at Banff 1910-1992

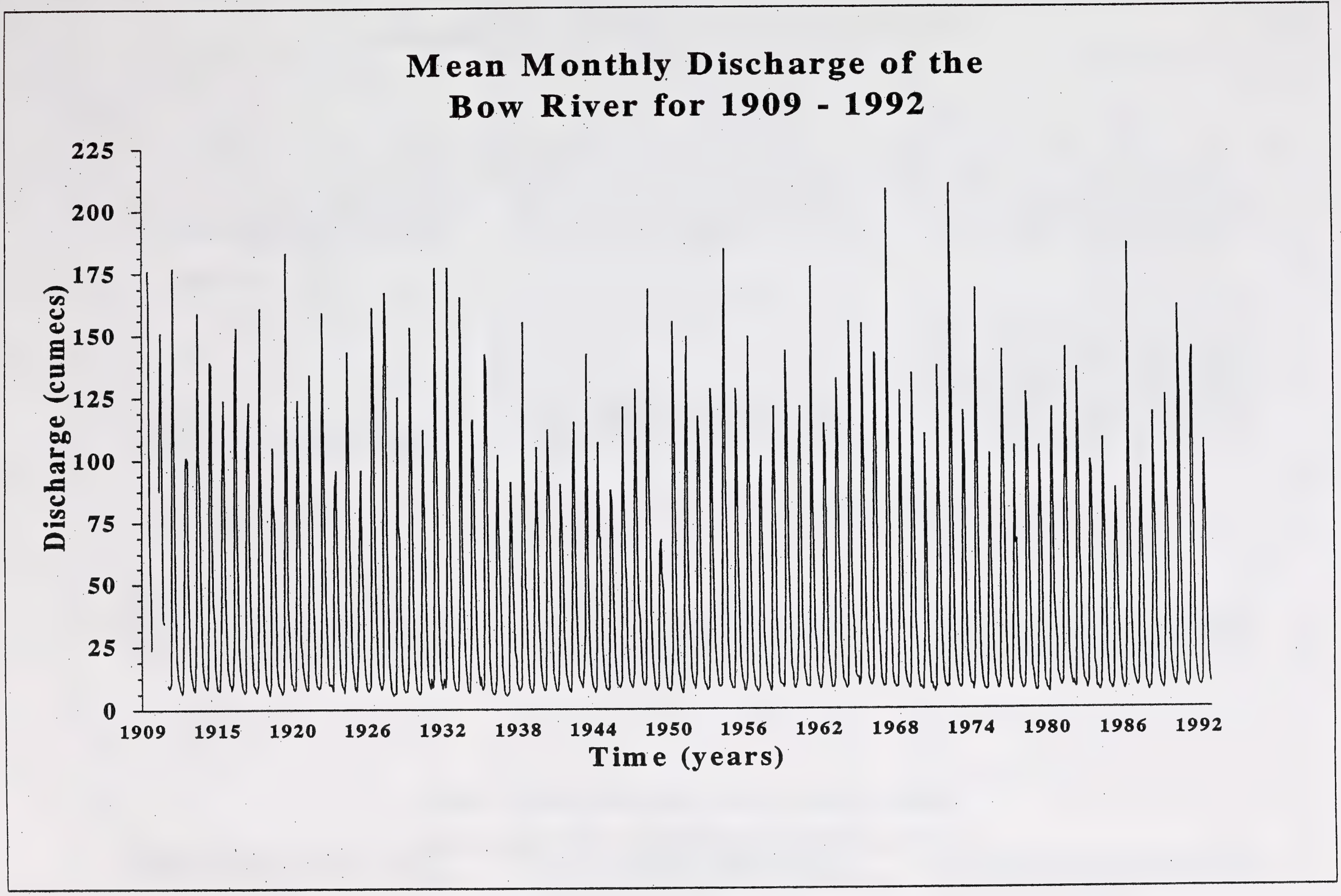


Fig. 2.3 Mean monthly discharge of the Bow River at Banff 1909-1992

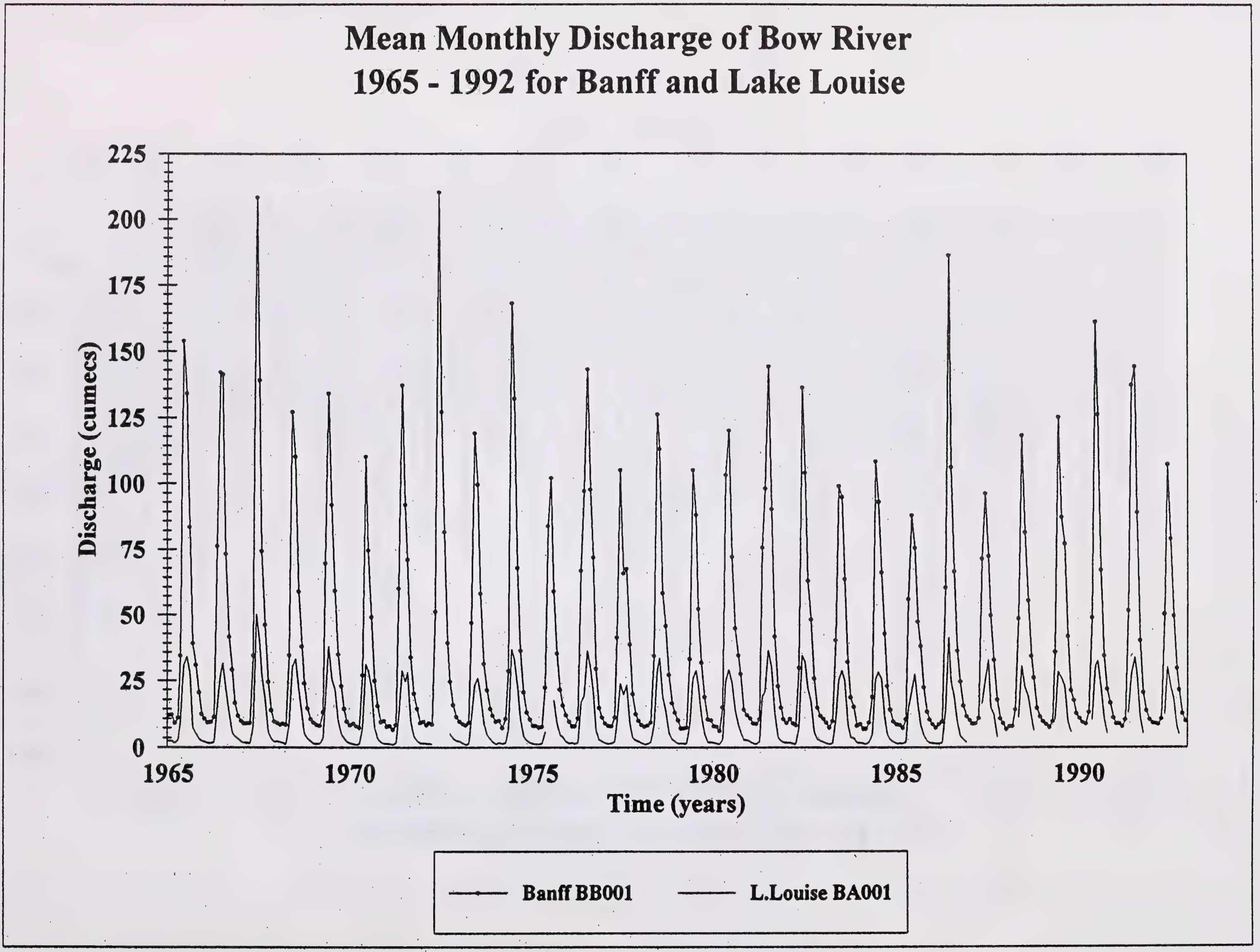


Fig. 2.4 Mean monthly discharge of the Bow River at Banff and for the Bow River at Lake Louise 1965-1992

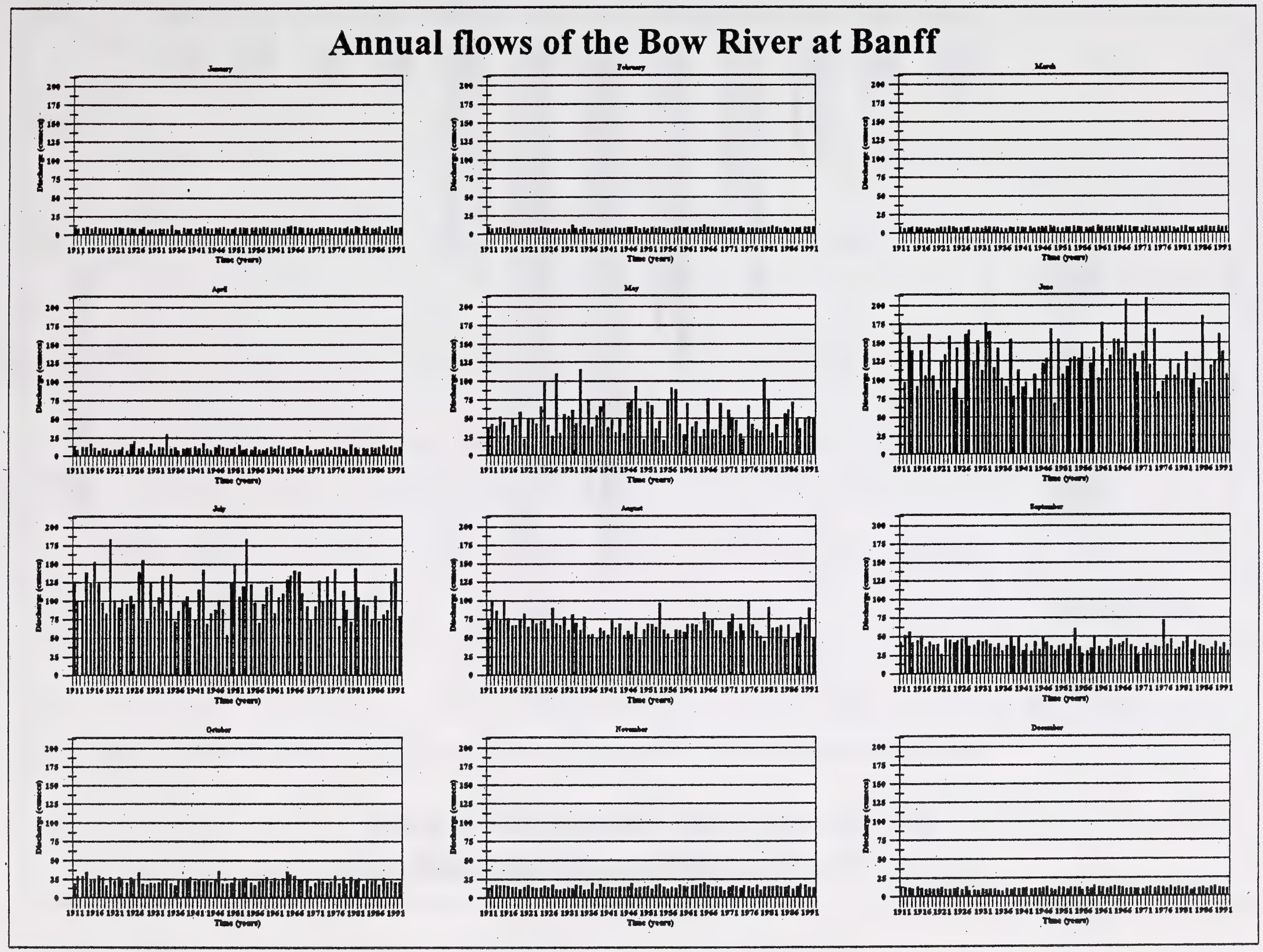


Fig. 2.5 Discharge of the Bow River at Banff by month 1910-1992

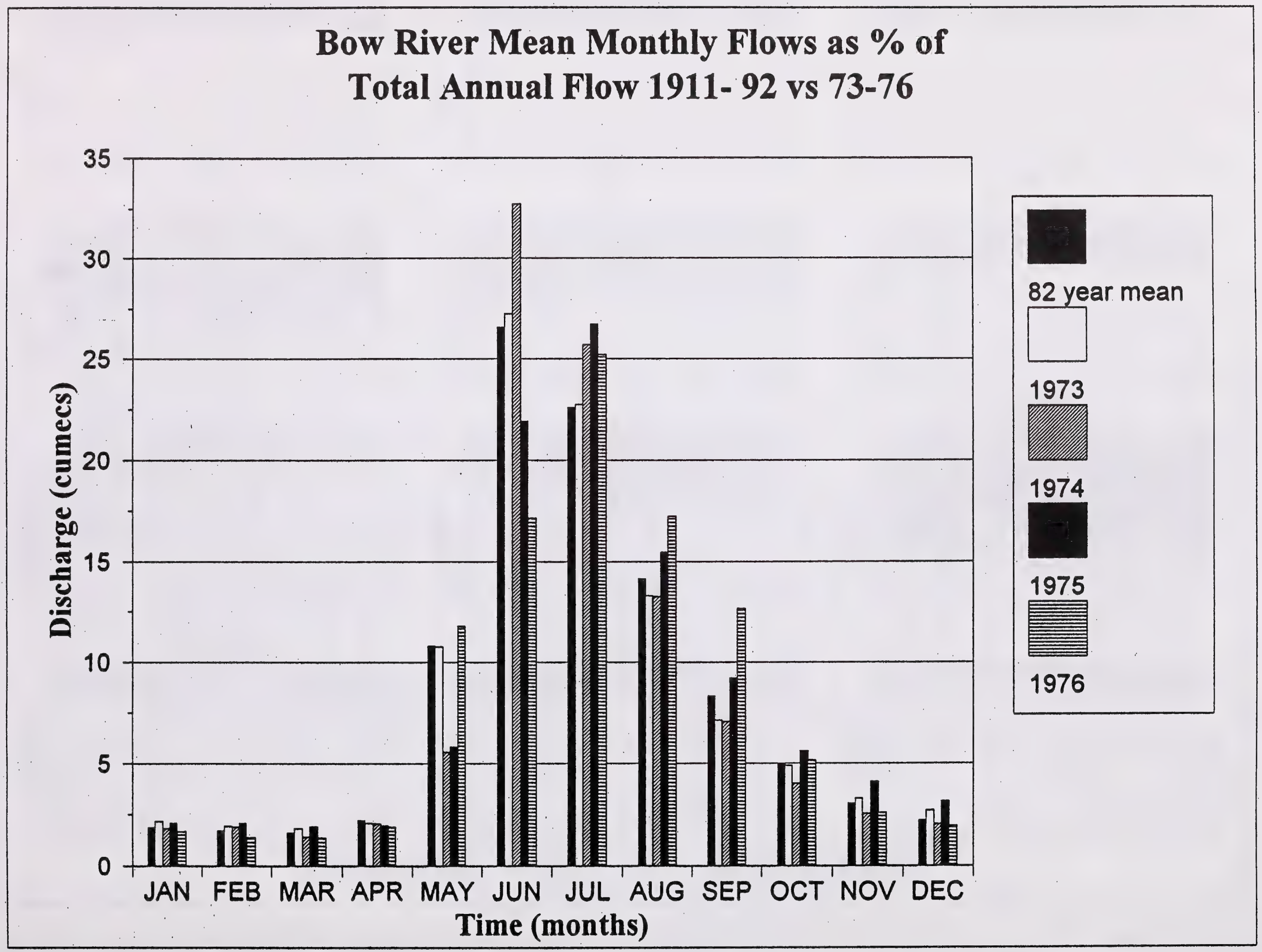


Fig. 2.6 Mean monthly flows of the Bow River at Banff 1973-76 as a percentage of the mean monthly flows 1911-1992

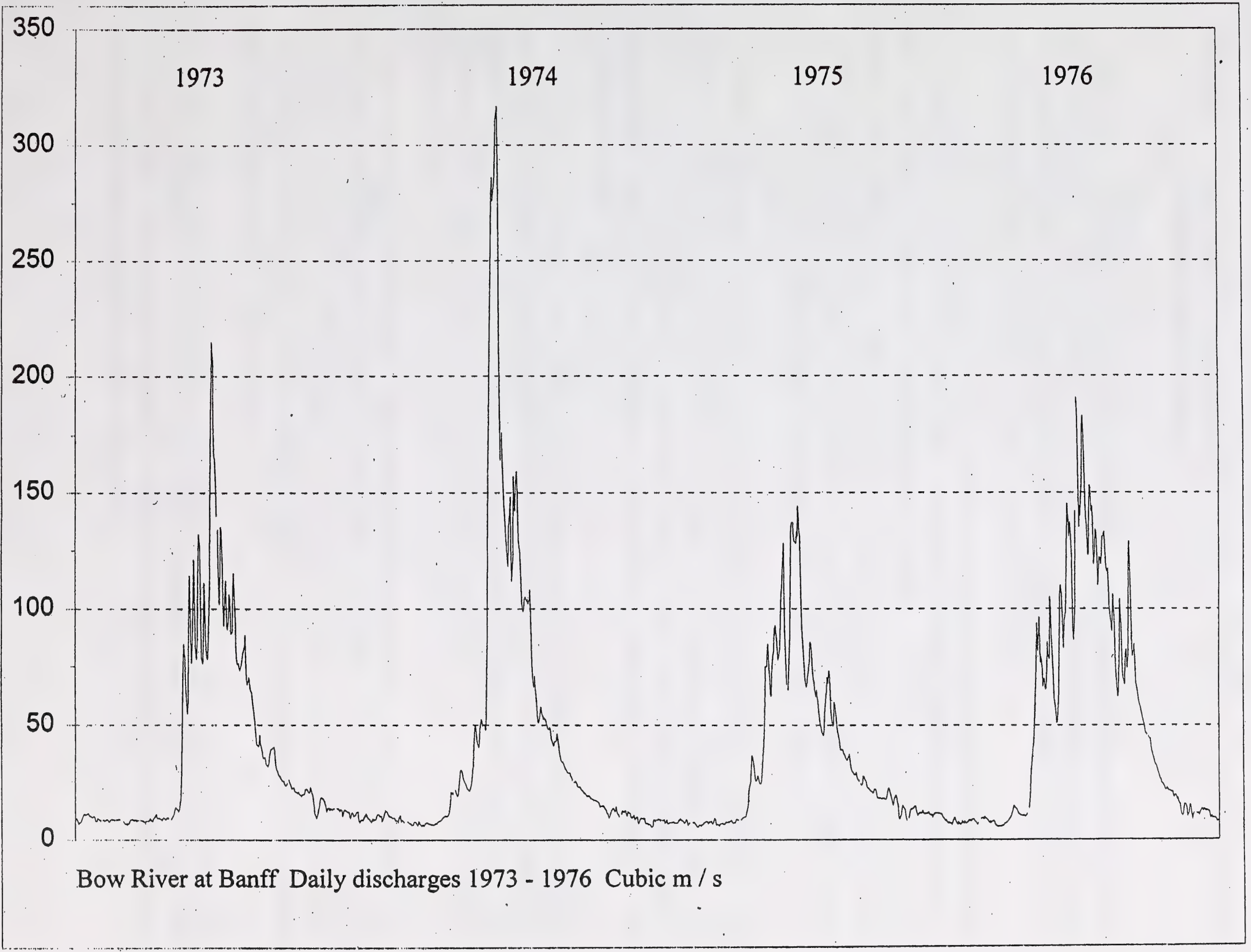


Fig. 2.7 Bow River at Banff daily discharge 1973-1976

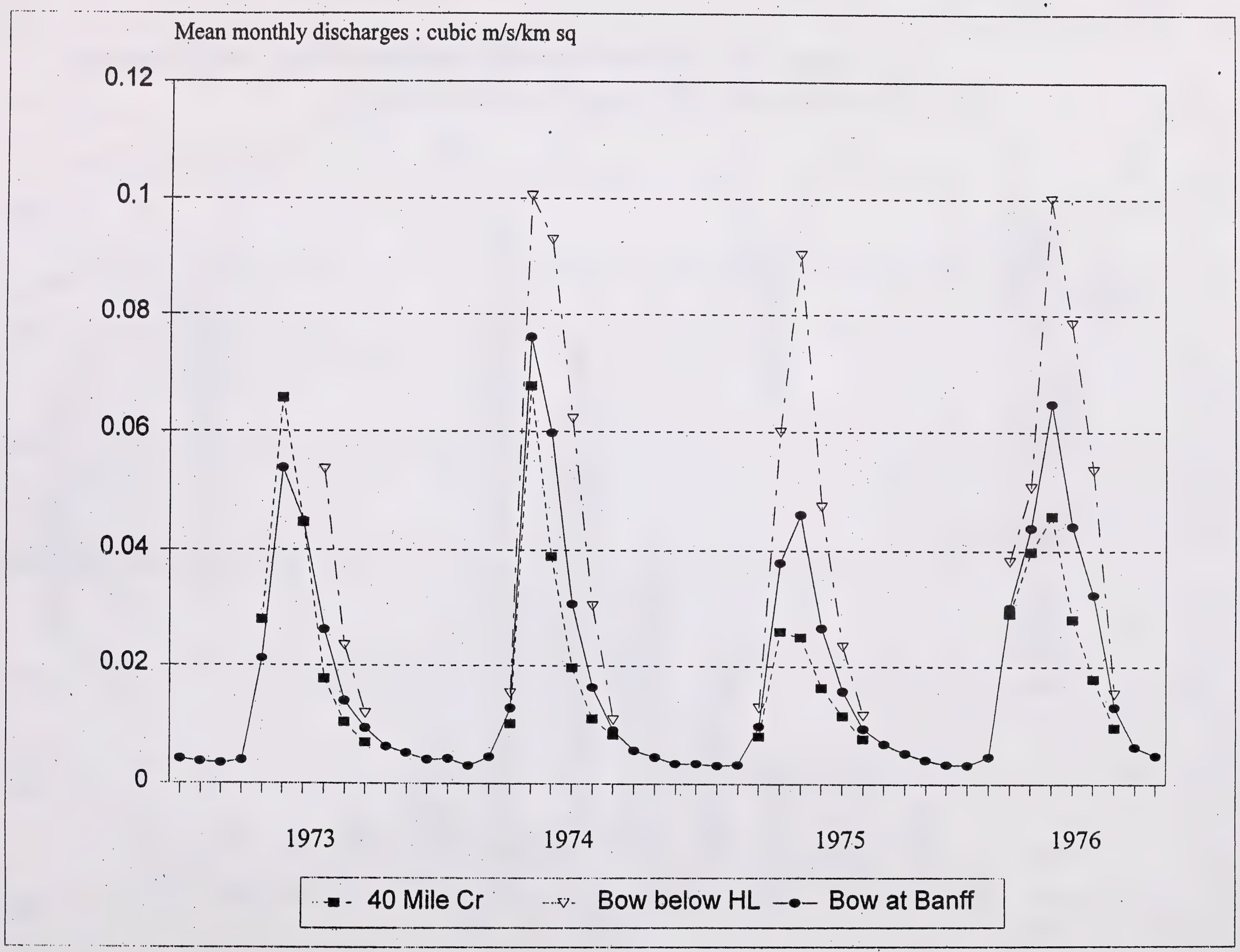


Fig. 2.8 Standardized mean monthly discharges 1973-1976 for the Bow River at Banff, the Bow below Hector Lake and Forty Mile Creek

Chapter 3 Database III: Meteorological records, snowcourse records and records of glacier mass balance

This chapter introduces the meteorological data available within the basin. Essentially only the high quality and consistent records of temperature and precipitation gathered over a long period of time are those from Banff. Great care must be taken when analysing climatic data records. It is known that the Lake Louise records are broken and must therefore be used with caution.

The Banff records are illustrated in fig. 3.1 showing annual temperature and precipitation records from 1895-1992. The temperature record (daily mean values are almost complete during the whole of this period, while the precipitation records are close to complete from 1910 onwards). It is, perhaps possible to detect a slow rise in temperature over this almost 100 year record. There are some periods of higher than average and lower than average temperatures. Of particular note was a marked cool period in the late 1940s. Precipitation shows an annual mean of about 450mm at Banff. The higher mountain areas show much higher mean annual precipitation often in the range 1200 - 1800 mm.

Records of temperature and other elements of the energy balance have been recorded at the Peyto Glacier research facility at 2200 masl, particularly for the period 1966-74. Records of glacier mass balance on Peyto Glacier cover an elevation range of 1000m and are illustrated in summary form in fig. 3.4.These data are not illustrated in detail within this report, but will be used in future analyses, especially for the determination of temperature and precipitation lapse rates, so important for many hydrological models.

Of particular importance for the understanding the hydrology of high mountain areas is the state of the snowpacks immediately prior to spring melt. Heavy winter snowpacks will produce increased runoff especially during the early summer period and may well decrease the contribution of glacier melt waters during the entire summer. Conversely, low winter snowpacks can lead to reduced overall summer flows, but can increase the yield and the relative importance of glacier ice melt.

Thus emphasis has been placed on the compilation of the snow course and the snow pillow data within the basin. A Time line for availability of snowcourse data is found in fig. 3.2. Table 3.1 and fig. 3.3 illustrate the April 1st records at some of the courses with long records. It will be noted from these summary presentations that there is a very strong covariance between the courses indicating a uniformity of snow inputs over the whole basin. This is an important finding as it will influence the types of basin modelling to be employed in future analyses.

Cautionary note: it was found that in several instances the computer files containing summary data were in error; sometimes errors were very great which could easily lead to erroneous analyses; these errors have been corrected as far as possible by reference to primary data files, but all data files will have to be rechecked for accuracy and consistency.

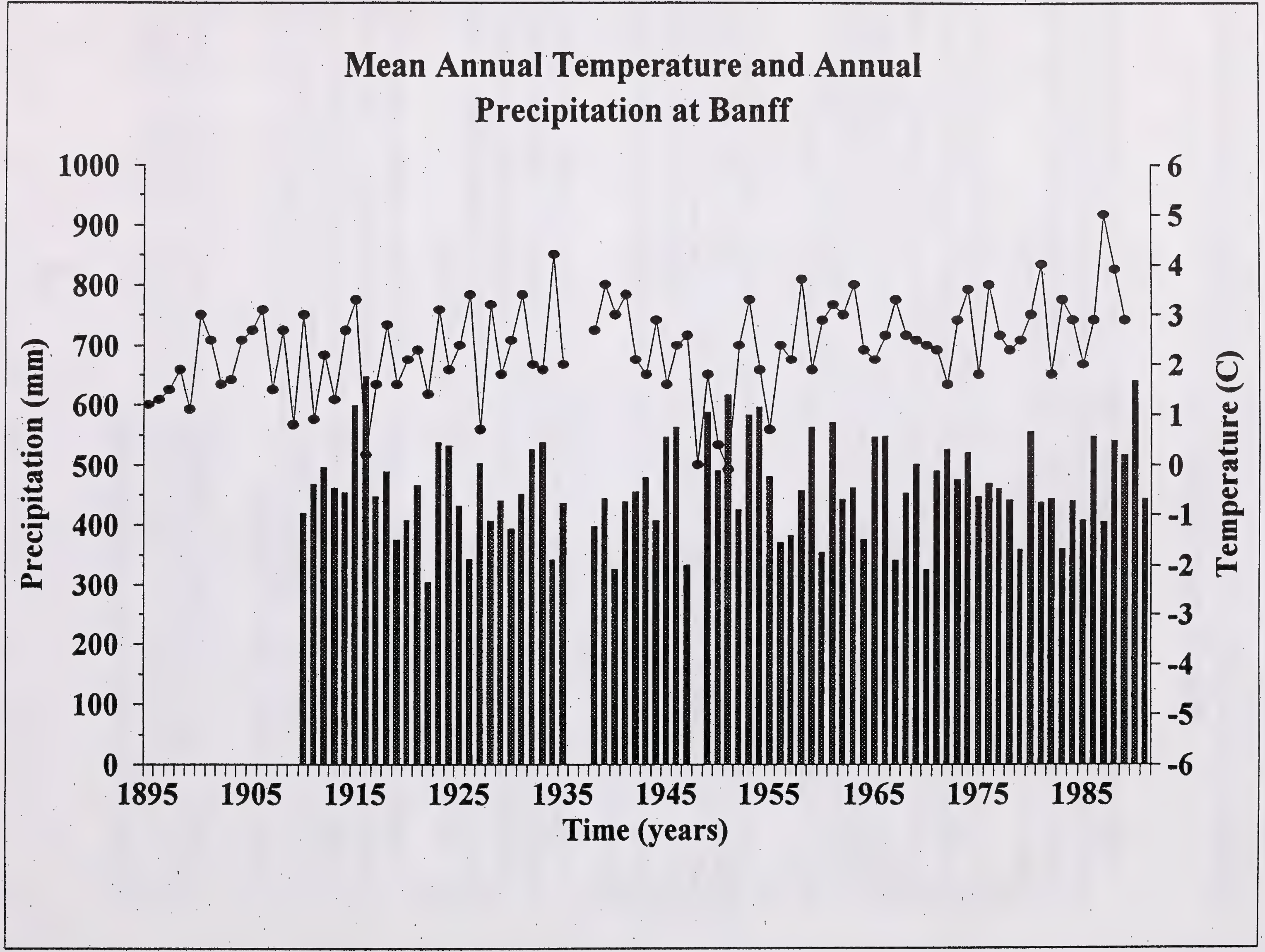
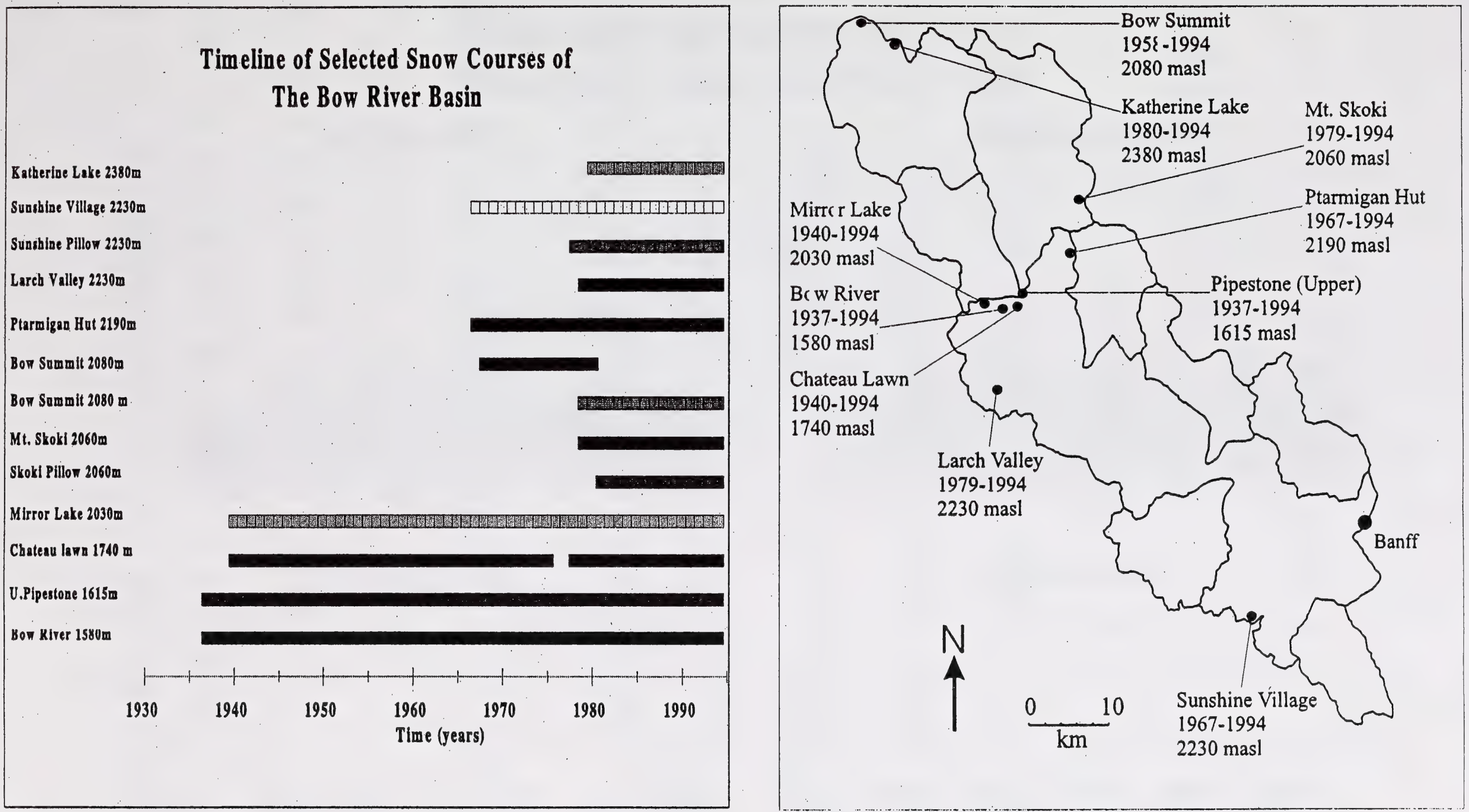


Fig. 3.1 Annual temperature and precipitation records at Banff, 1895-1992



(a)

(b)

Fig. 3.2(a) Timeline of data availability and (b) location of selected snow courses

Snow course data 1937 - 1989 for April 1 surveys

	Bow River (1580m)	Chateau Lawn (1740m)	Mirror Lake (2030m)	Pipestone Upper (1615m)		Bow River (1580m)	Chateau Lawn (1740m)	Mirror Lake (2030m)	Pipestone Upper (1615m)	Bow Summit (old) (2080m)	(new) (2080m)	(composite) (2080m)
1937	97			117	1964	137	178	193	152			
1938	208			282	1965	284	323	378	259			
1939	180			183	1966	213	226	274	193			
1940	132	142	168	142	1967	437	478	538	434			
1941	135	135	203	150	1968	170	234	254	163	328		458
1942	114	173	180	117	1969	196	310	320	208			
1943	168	178	224	160	1970	119	152	163	109	127		177
1944	137	157	178	137	1971	259	356	368	251	323		451
1945	104	173	160	127	1972	386	480	561	406	546		763
1946	216	277	353	234	1973	175	325	279	150	300		419
1947	241	282	358	246	1974	277	381	419	193	533		745
1948	229	292	310	234	1975	203	257	236	190	264		369
1949	160	239	211	147	1976	269		361	251	460		643
1950	274	384	427	292	1977	147		175	114	170		237
1951	274	389	460	338	1978	198	216	244	175	310		433
1952	229	262	315	226	1979	191	259	234	198	251	361	361
1953	213	300	274	218	1980	232	333	320	234	320	434	434
1954	330	391	452	218	1981	244	328	318	246		381	381
1955	163	229	239	160	1982	234	300	295	284		353	353
1956	323	373	427	310	1983	206	277	284	229		340	340
1957	269	307	378	264	1984	142	196	239	152		330	330
1958	218	267	297	216	1985	175	211	211	196		315	315
1959	259	305	310	264	1986	236	290	345	287		439	439
1960	150	160	262	145	1987	218	279	302	221		302	302
1961	224	310	333	236	1988	160	213	251	191		320	320
1962	206	264	279	198	1989	196	292	284	234		384	384
1963	147	188	218	152								

Table 3.1 April 1st water equivalents (mm) for selected snowcourses 1937-1989

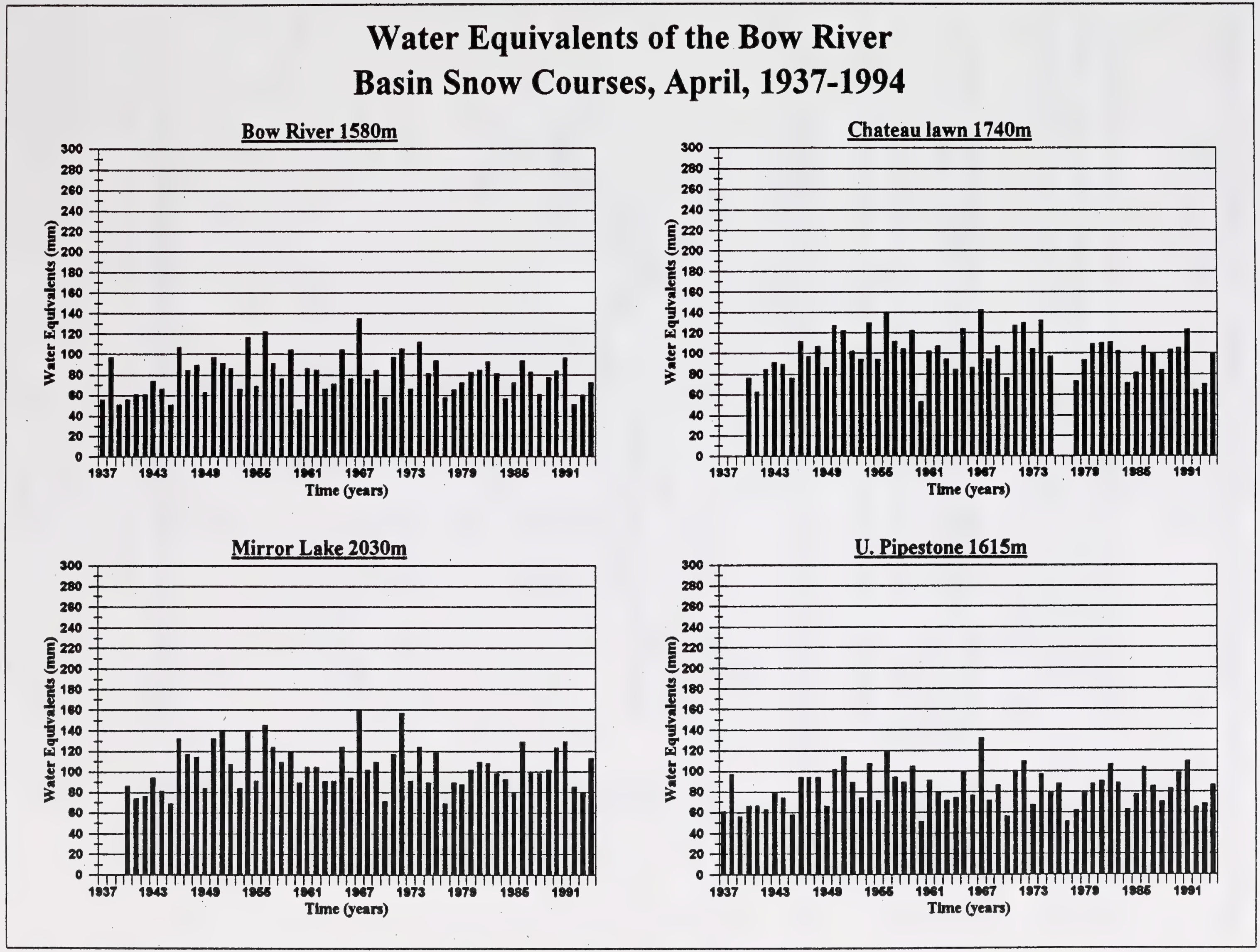


Fig. 3.3 April 1st water equivalents (mm) for the four snowcourses with the longest records

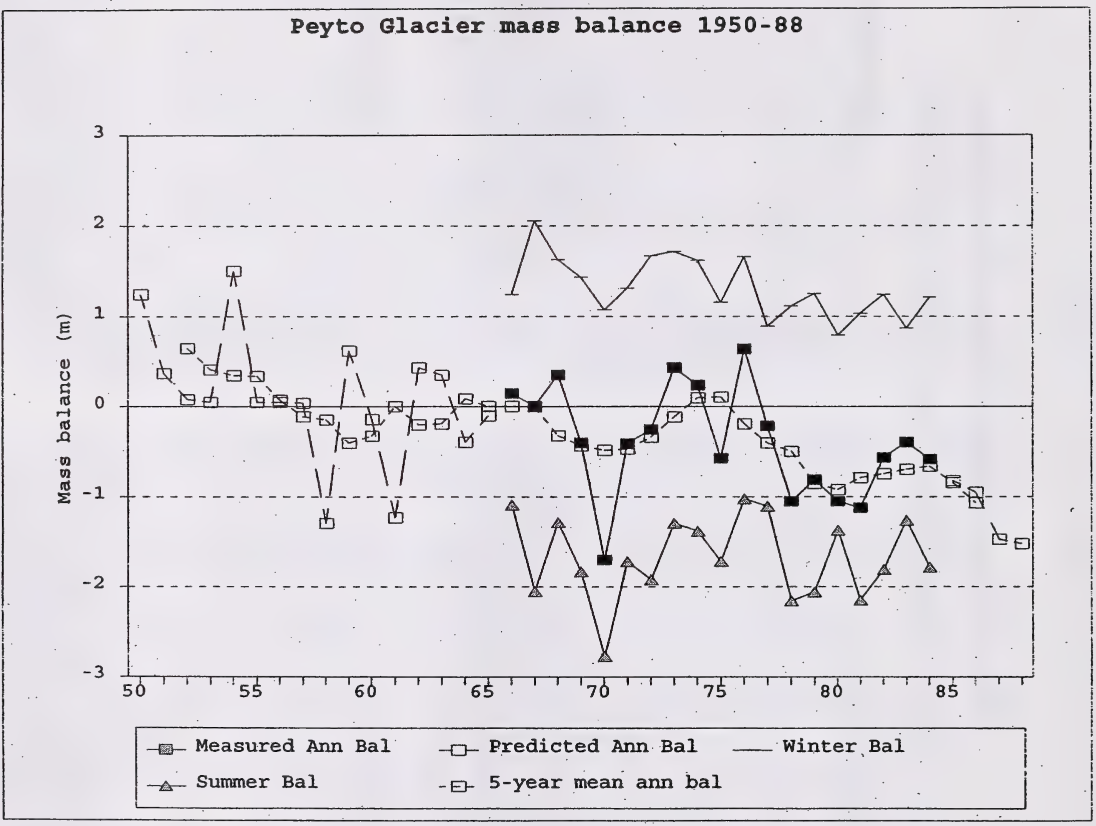


Fig. 3.4 Peyto Glacier mass balance 1966-84, with extrapolations back to 1950

Chapter 4 Database IV: Glacier inventory and selected coverage by aerial photography

It had been hoped that considerably more progress in compiling data from the Canadian Glacier Inventory would have been achieved. Unfortunately the data archives within the National Hydrology Research Institute could not readily be accessed. Illustration of the glacier coverage within the Bow basin as defined and referenced within the Glacier Inventory is given in fig. 4.1.

Data for the glacier inventory for the Waputik Mountain area (within the western section of the Lake Louise sub-basin) are available from Müller et al 1967. The map from this publication is given in fig. 4.2 and summary statistics from the publication are given in table 4.1. It will be noted that the glacier reference numbers within the maps in figs. 4.1 and 4.2 are not consistent. This aspect of the glacier inventory work needs to be rectified before future analyses may be undertaken.

Over the last few decades many surveys using air photography have been conducted. Some of these surveys are illustrated in figs 4.2(a,b and c).

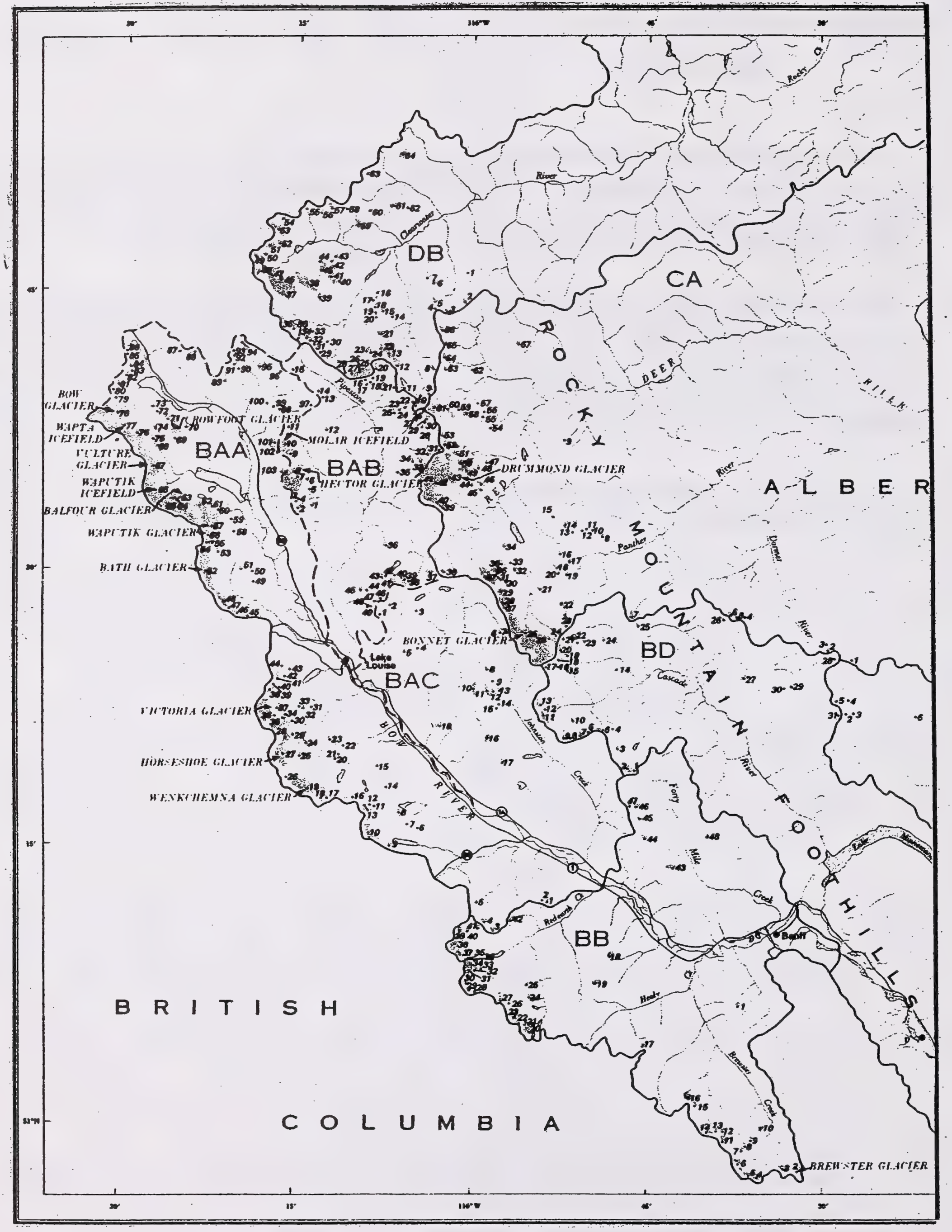


Fig. 4.1 Glacier inventory base map of the Upper Bow River and adjacent basins from the Glacier Atlas of Canada

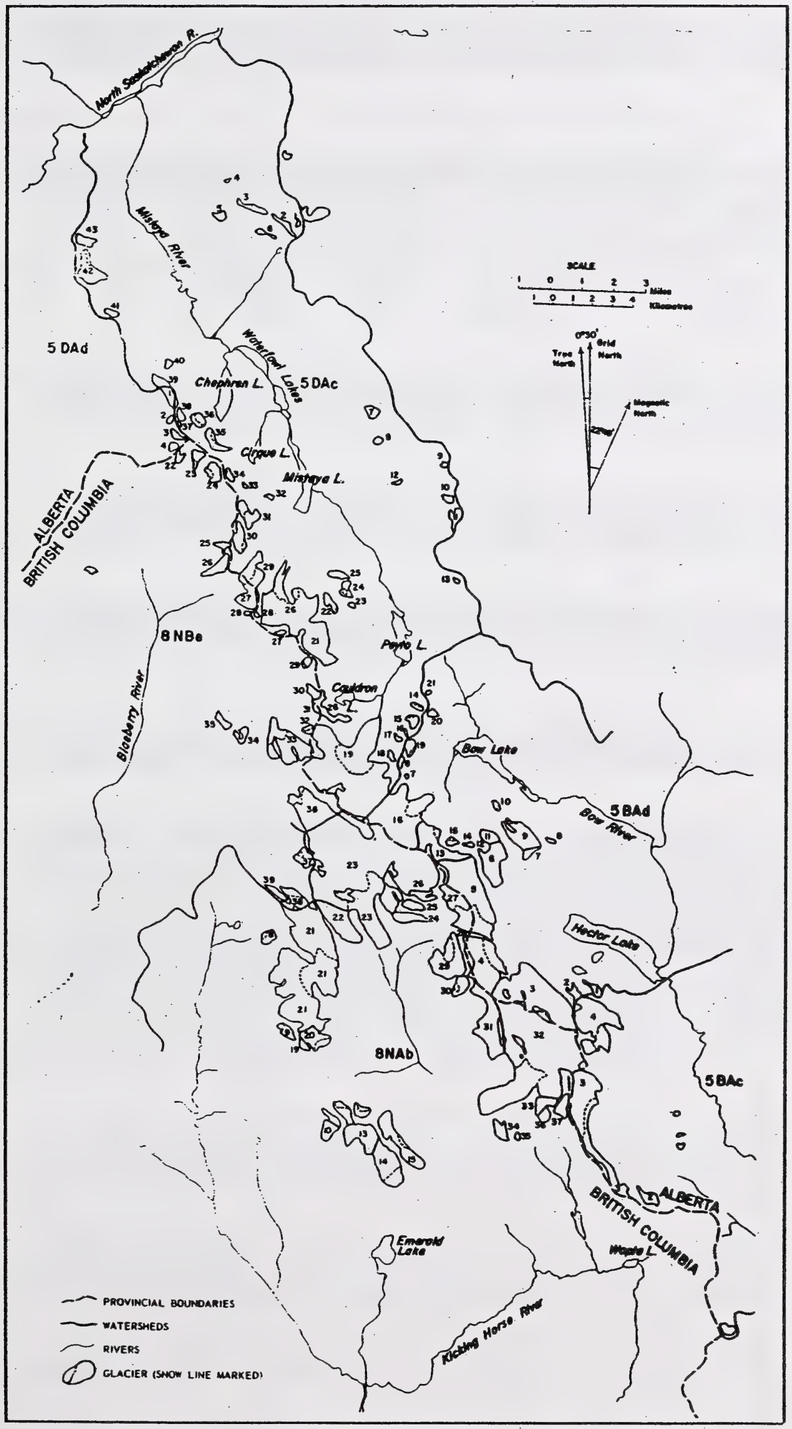


Fig. 4.2 Map of the Glacier Inventory of the Waputik Mountains from Müller et al 1967

Bow River Headwaters

Ident	No.	Longitude	Latitude	U.T.M	Orientation		Elevations				Date	Mean Elevation	
					AC	AB	High	L.Ex	L.Tl	Snow		Accumulation	Ablation
5BAC	2	w 116 20.0	n 51 28.0	11UNH546257021	N	N	2347	2134	2134		22 08 66	2225	
5BAC	3	w 116 23.0	n 51 30.5	11UNH543157063	S	SE	2774	2347	2347	2499	22 08 66	2652	2499
5BAC	4	w 116 22.5	n 51 33.0	11UNH543557126	SE	SE	2713	2225	2225	2469	22 08 66	2530	2347
5BAC	5	w 116 18.5	n 51 29.5	11UNH547857047	N	N	2605	2499	2499		22 08 66	2591	
5BAC	6	w 116 18.5	n 51 30.0	11UNH547857053	E	E	2377	2195	2195		22 08 66	2347	
5BAC	7	w 116 19.0	n 51 30.5	11UNH547757064	NE	E	2225	2103	2103		22 08 66	2195	
5BAD	1	w 116 22.5	n 51 34.0	11UNH543357126	N	NW	2804	2225	2225		22 08 66	2682	
5BAD	2	w 116 23.5	n 51 34.0	11UNH542357123	N	NW	2774	2347	2347		22 08 66	2652	
5BAD	3	w 116 25.0	n 51 34.0	11UNH540257126	N	NW	3048	2134	2134	2438	22 08 66	2652	2286
5BAD	4	w 116 27.5	n 51 34.5	11UNH537857141	N	NE	3048	2286	2286	2530	22 08 66	2896	2530
5BAD	5	w 116 27.5	n 51 35.5	11UNH537457160	SE	SE	2830	2330	2330	2530	22 08 66	2713	2499
5BAD	6	w 116 27.5	n 51 37.0	11UNH537957187	SW	SE	2865	2445	2445	2591	22 08 66	2743	2530
5BAD	7	w 116 25.5	n 51 37.5	11UNH539757193	S	S	2743	2575	2575		22 08 66	2698	
5BAD	8	w 116 26.0	n 51 38.0	11UNH540857200	NE	NE	2377	2316	2316		22 08 66	2347	
5BAD	9	w 116 26.0	n 51 38.0	11UNH539457202	NW	N	2743	2408	2408	2438	22 08 66	2682	2499
5BAD	10	w 116 27.0	n 51 38.5	11UNH538057217	SE	E	2438	2286	2286	2347	22 08 66	2408	2316
5BAD	11	w 116 27.5	n 51 38.0	11UNH537757202	NW	NW	2896	2575	2575		22 08 66	2790	
5BAD	12	w 116 27.5	n 51 37.5	11UNH537257194	NW	NW	2743	2682	2682		22 08 66	2713	
5BAD	13	w 116 30.0	n 51 38.0	11UNH534657203	N	N	2926	2469	2469	2560	22 08 66	2665	2530
5BAD	14	w 116 28.0	n 51 37.5	11UNH535757198	NW	NW	2591	2452	2452	2499	22 08 66	2499	2499
5BAD	15	w 116 29.0	n 51 38.0	11UNH535857198	N	N	2438	2256	2256	2316	22 08 66	2377	2286
5BAD	16	w 116 30.5	n 51 39.0	11UNH533957216	NE	NE	2774	2317	2317	2560	22 08 66	2652	2484
5BAD	17	w 116 31.0	n 51 39.5	11UNH533457233	E	E	2804	2652	2652		22 08 66	2743	
5BAD	18	w 116 31.5	n 51 40.0	11UNH533257240	E	E	2896	2713	2713		22 08 66	2758	
5BAD	19	w 116 31.0	n 51 40.5	11UNH533657246	SE	SE	2743	2576	2576	2606	22 08 66	2652	2591
5BAD	20	w 116 30.0	n 51 41.5	11UNH535657264	NE	NE	2591	2469	2469		22 08 66	2560	
5BAD	21	w 116 30.0	n 51 42.0	11UNH534557276	N	N	2499	2377	2377		22 08 66	2438	

Bow River Headwaters

Ident	No.		Total Length		Width		Surface Area				AAR	Depth	Volume	**	Type
		Ablation	Exp	Total		Exp	Total		Ablation						
5BAC	2		0.4	0.4		0.34	0.34	2			100	10	0.003	3	600010
5BAC	3	0.2	3.1	3.1	1.5	4.3	4.3	2	0.34	2	92	50	0.215	3	600010
5BAC	4	1.3	3.2	3.2	0.8	2.9	2.9	2	0.59	2	79	50	0.145	4	520012
5BAC	5		0.3	0.3		0.06	0.06	2			100	10	0.001	4	600010
5BAC	6		0.4	0.4	0.2	0.08	0.08	2			100	10	0.001	4	600000
5BAC	7		0.4	0.4	0.2	0.05	0.05	2			100	10	0.001	4	640010
5BAD	1		0.6	0.6	0.4	0.27	0.27	2			100	10	0.003	4	640402
5BAD	2		0.8	0.8	0.4	0.31	0.31	2			100	10	0.003	4	603312
5BAD	3	1.5	3.9	3.9	1.2	5.9	5.9	2	1.7	2	71	70	0.413	3	520412
5BAD	4	0.5	2.7	2.7		2.9	2.9	2	0.8	2	74	70	0.203	3	503311
5BAD	5	1.3	3.2	3.2	1	4.9	4.9	2	1	2	79	70	0.343	4	503012
5BAD	6	1.1	1.9	1.9	0.8	1.5	1.5	2	0.44	2	71	50	0.008	4	530010
5BAD	7		0.5	0.5	0.2	0.25	0.25	2			100	10	0.002	4	600012
5BAD	8		0.4	0.4		0.12	0.12	2			100	10	0.001	4	600010
5BAD	9	0.1	1.6	1.6	0.7	1.5	1.5	2	0.06	2	66	25	0.004	4	600212
5BAD	10	0.1	0.6	0.6	0.2	0.14	0.14	2			100	10	0.001	4	630000
5BAD	11		1	1	0.7	0.45	0.45	2			100	10	0.004	4	600010
5BAD	12		0.3	0.3	0.2	0.06	0.06	2			100	10	0.001	4	600310
5BAD	13	0.3	2.6	2.6	0.7	2	2	2	0.09	2	95	25	0.05	4	600210
5BAD	14	0.1	0.4	0.4		0.11	0.11	2	0.02	2	80	10	0.001	4	640002
5BAD	15	0.2	0.5	0.5		0.27	0.27	2	0.06	2	78	10	0.003	4	640002
5BAD	16	1.6	3.1	3.1	0.5	5.1	5.1	2	0.52	2	90	100	0.51	3	523411
5BAD	17		0.2	0.2		0.06	0.06	2			100	10	0.001	4	640000
5BAD	18		0.2	0.2		0.2	0.2	2			100	10	0.002	4	630010
5BAD	19	0.1	0.7	0.7		0.38	0.38	2	0.08	2	79	10	0.004	4	630002
5BAD	20		0.5	0.5		0.19	0.19	2			100	10	0.002	4	640000
5BAD	21		0.3	0.3		0.6	0.6	2			100	10	0.001	4	600012
		6.9	26		7	27.21			4.77				1.56		

** Note - For volume accuracy rating "4" read "3" and for "3" read "2"

Summary of the glacier inventory of the Bow River headwaters of the Waputik Mountains

Location	No.	Volume cubic k	Area square km	Max. size square km	Highest	Terminus	Elevation Transient snow line From	To
5Bac	6	0.366	7.73	4.3	2800	2100	2450	
5Bad	21	1.56	27.21	5.9	2900	2100	2350	2600

Table 4.1 Summary data from glacier inventory of the Waputik Mountains from Müller et al 1967

Table 4.2(a) Air Photographs from 1951 - 1952 Scale 1:40 000

Flight Line	Year flown	Photograph Numbers
AS162-5110	1951	124-136
AS162-5110	1951	195-208
AS163-5109	1951	54-66
AS163-5108/09	1951	20-33
AS164-5108	1951	140-155
AS164-5107	1951	5-11
AS165-5106/07	1951	224-235
AS165-5106	1951	78-90
AS166-5105	1951	174-185
AS166-5104	1951	38-50
AS166-5103/04	1951	14-25
AS167-5103	1951	152-158
AS167-5102	1951	26-30
AS168-5101	1951	128-135
AS168-5100	1951	1-6
AS169-5200	1952	104-110

Table 4.2(b) Air Photographs from the year 1977 July / August, Scale 1:50 000

Flight Number	Photograph Numbers
A24783	55-79
A24783	71-85
A24783	95-110
A24776	134-140
A24776	65-70
A24805	105-115
A24805	55-61
A24739	100-105
A24783	125-136

Table 4.2(c) Air Photographs from the year 1993,September, Scale 1:50 000

Flight Number	Photograph Numbers	
A27991	94-104	
A27991	10-19	
A27988	284-293	Partial Cloud
A27988	262-255	259-260 Cloud
A27988	205-216	209-210 Cloud
A27988	118-129	

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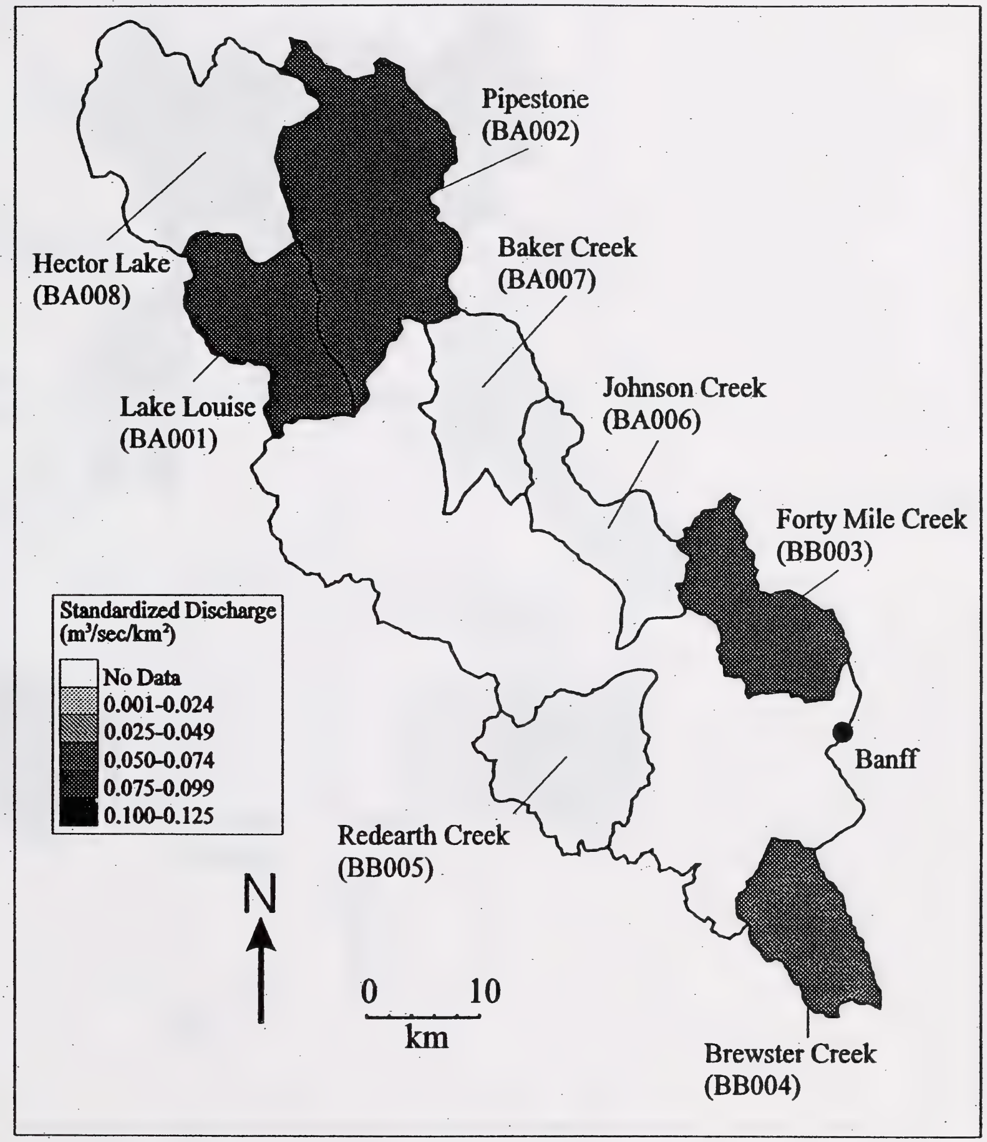
Appendix Specific yield from sub-basins June, July, August, September, 1973-76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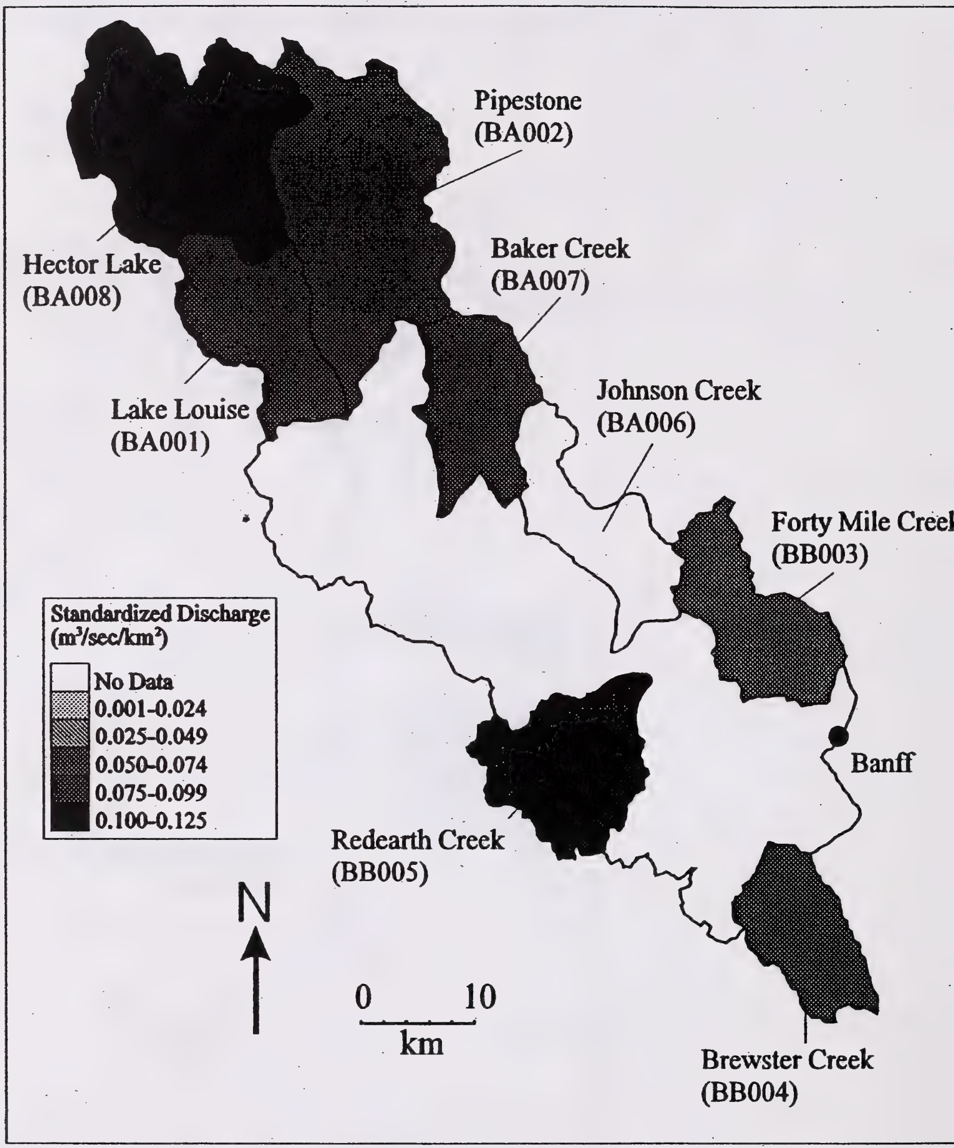
A.1 June 1973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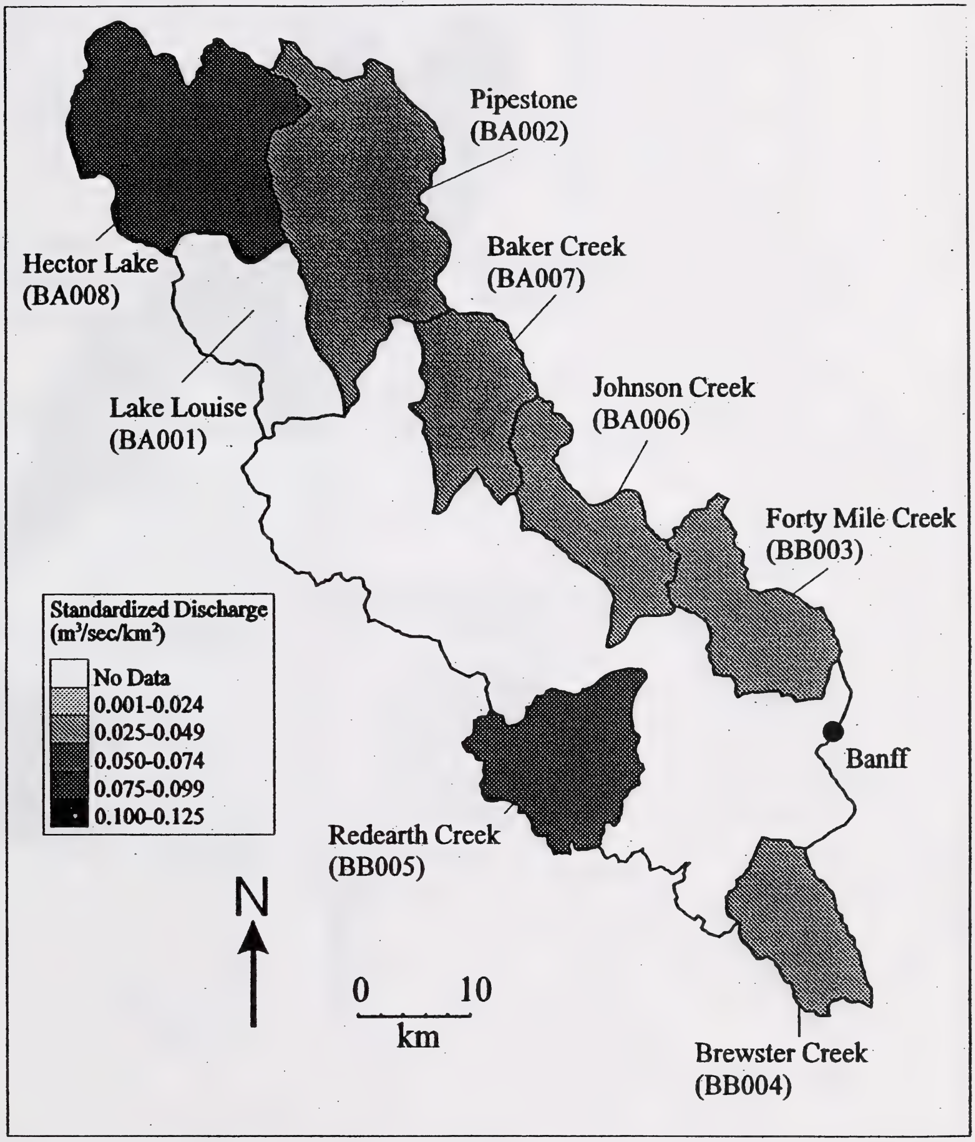
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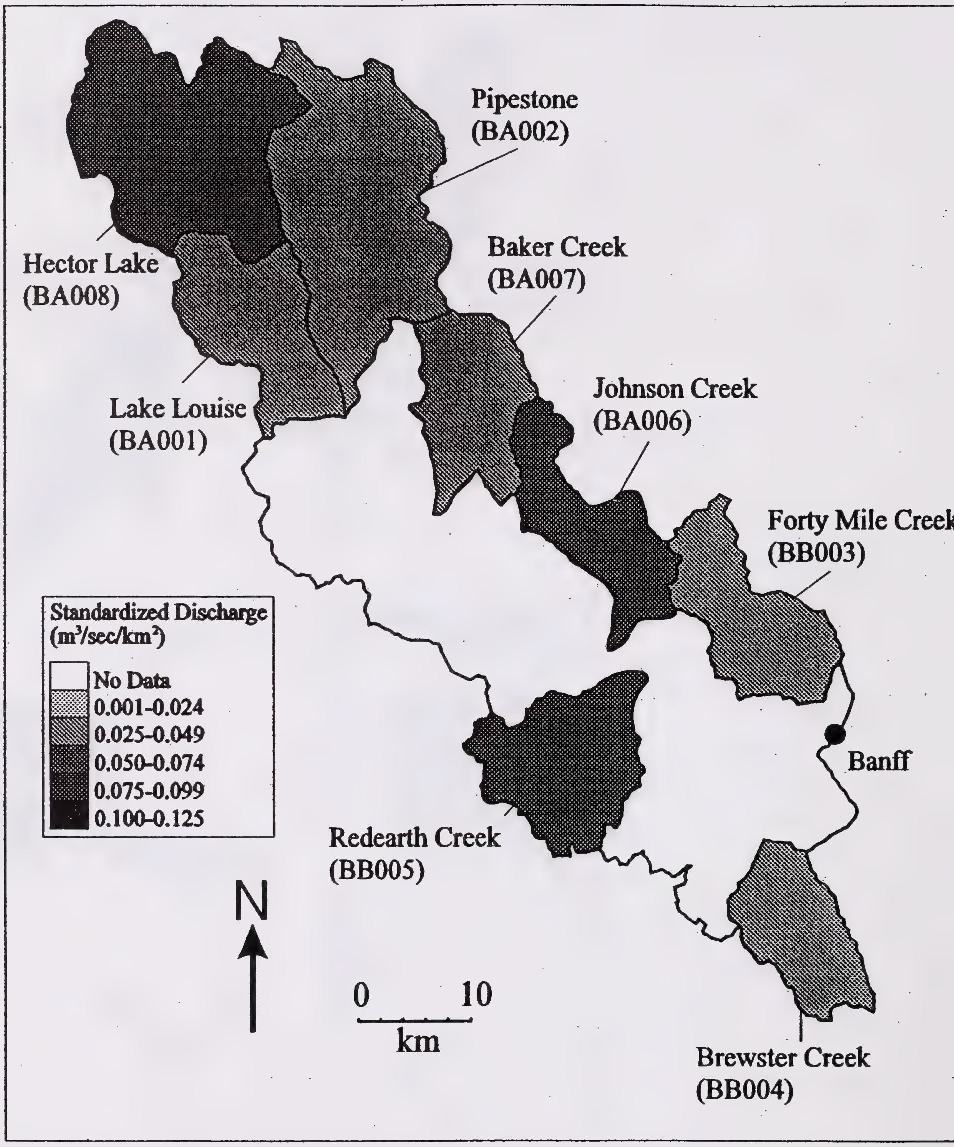
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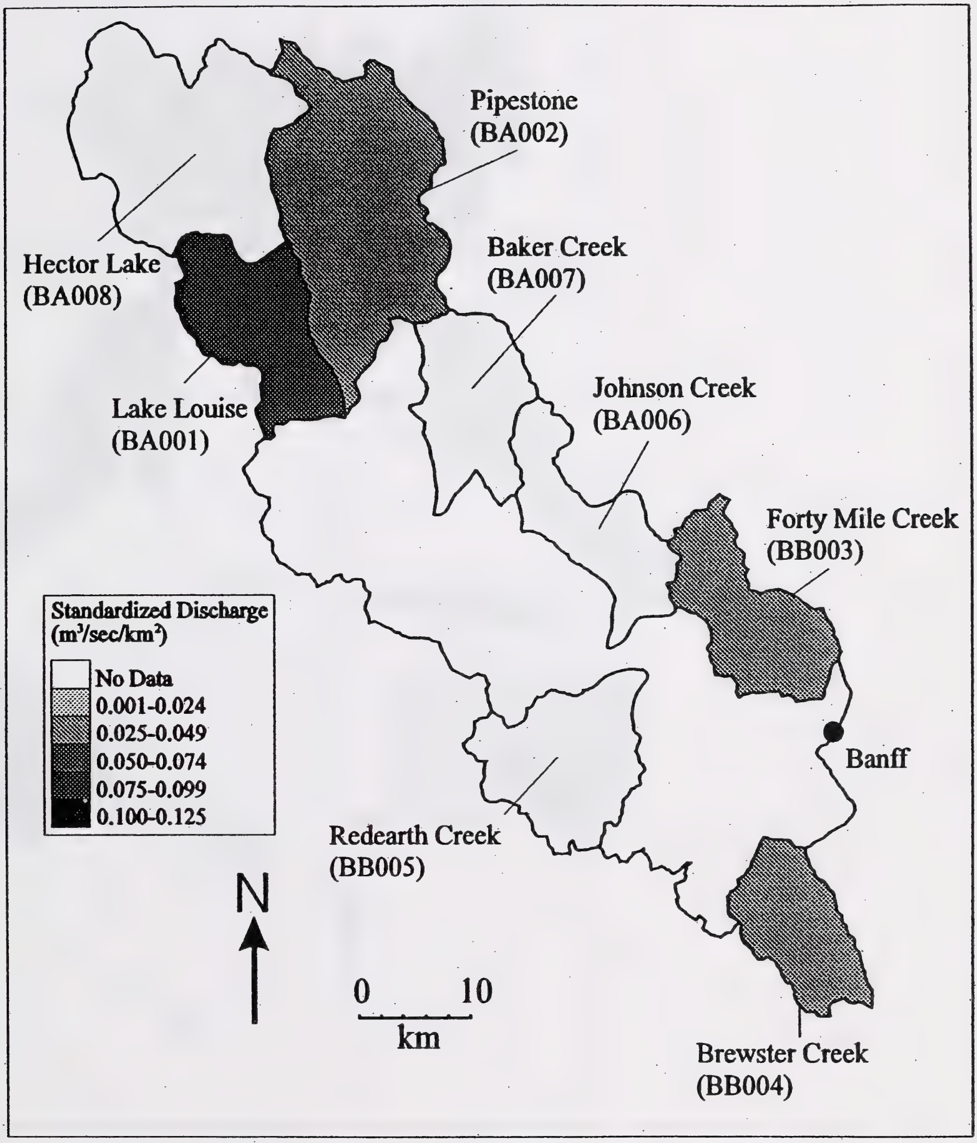
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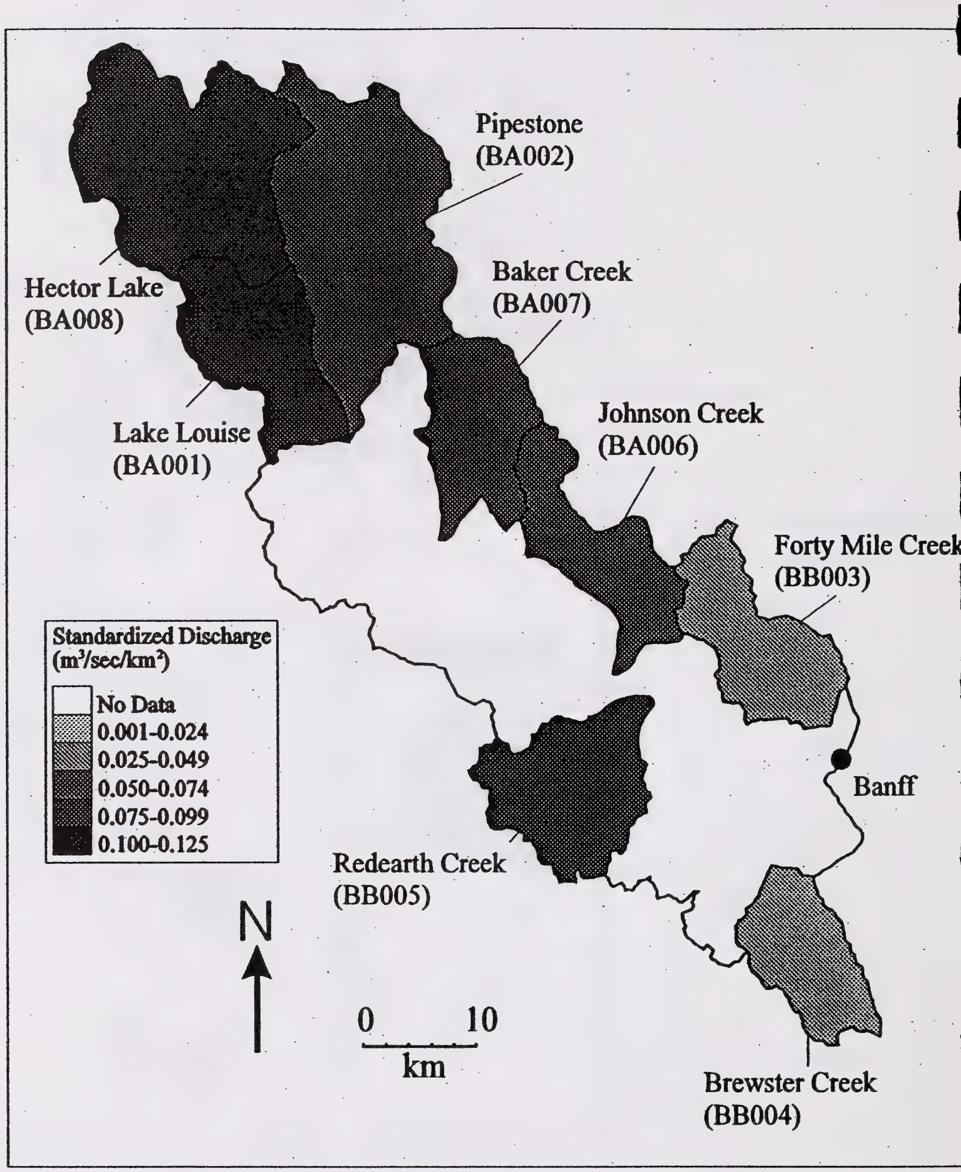
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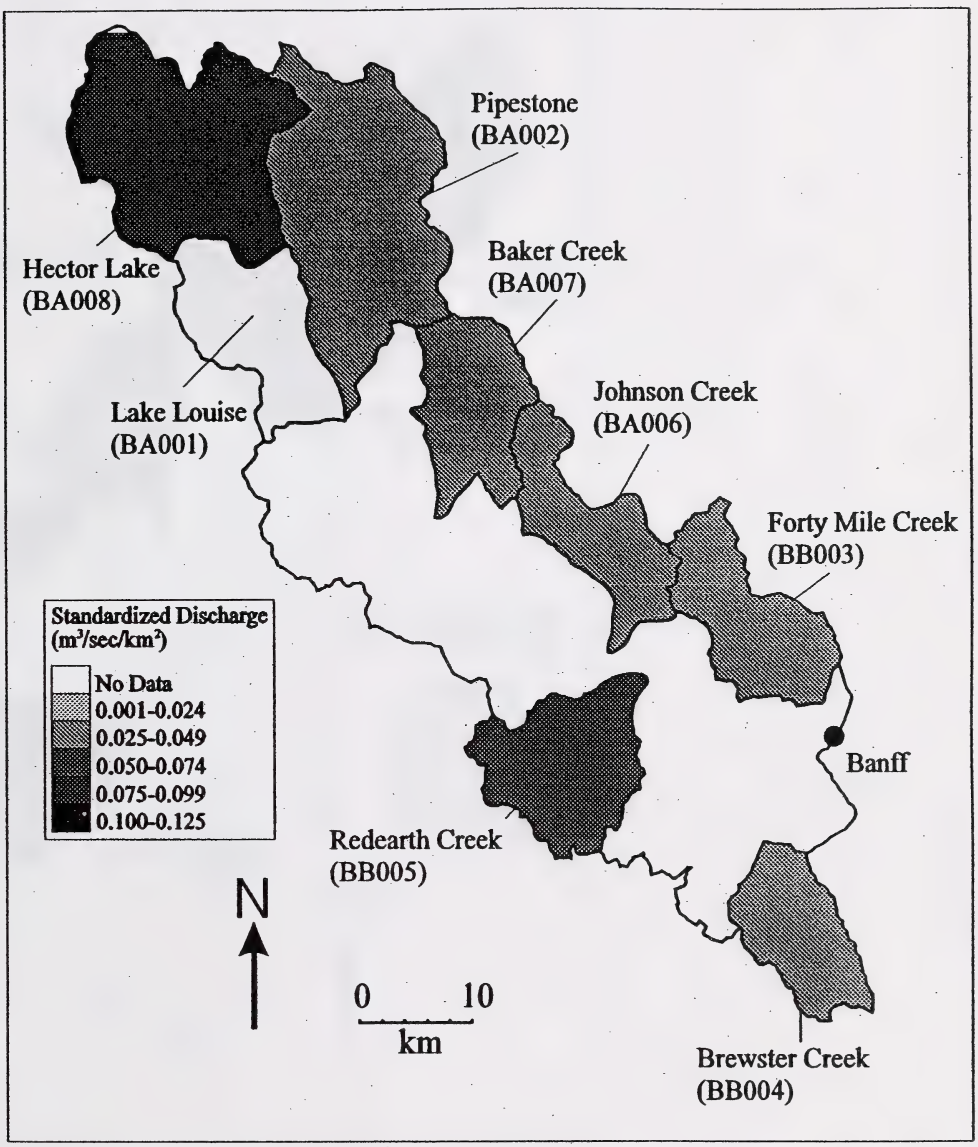
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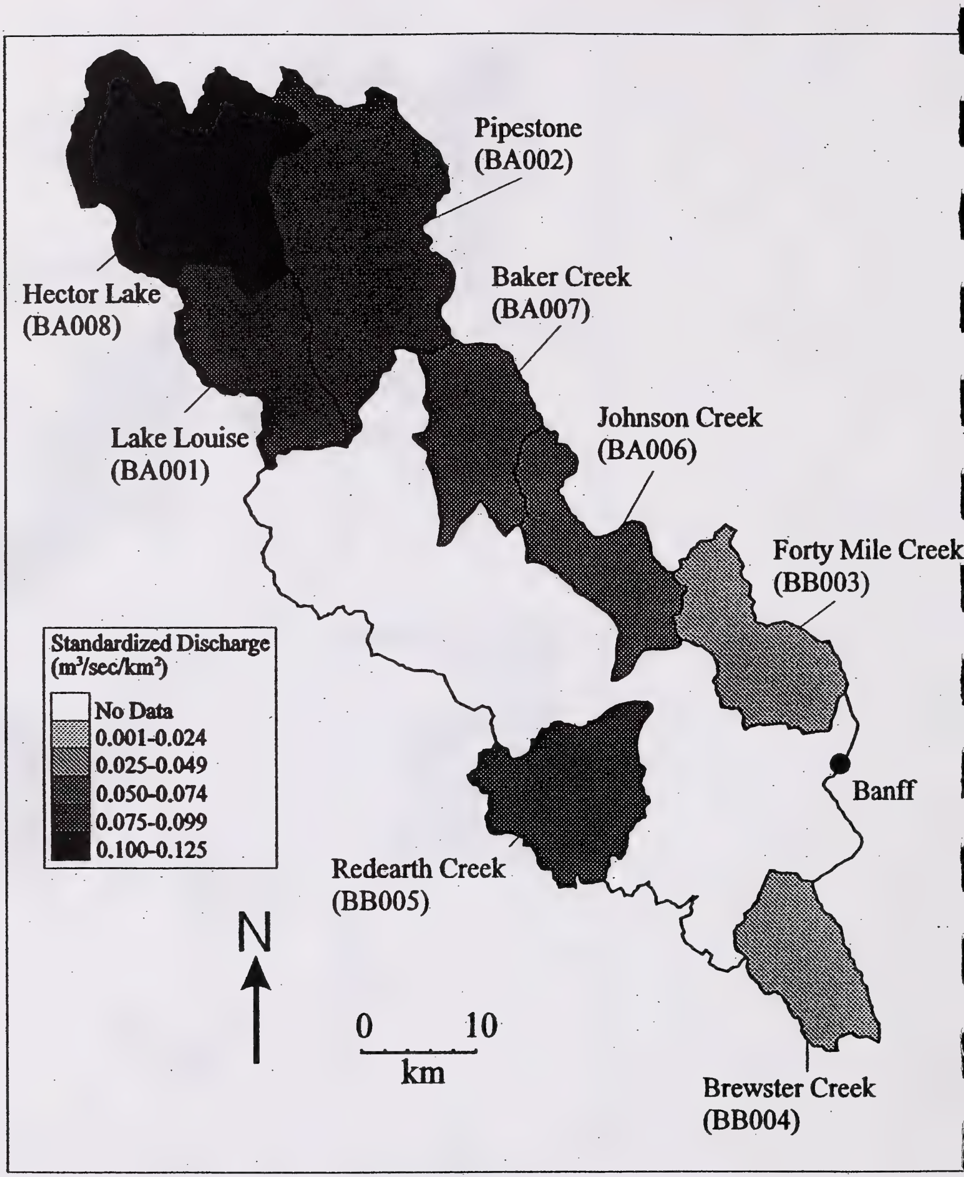
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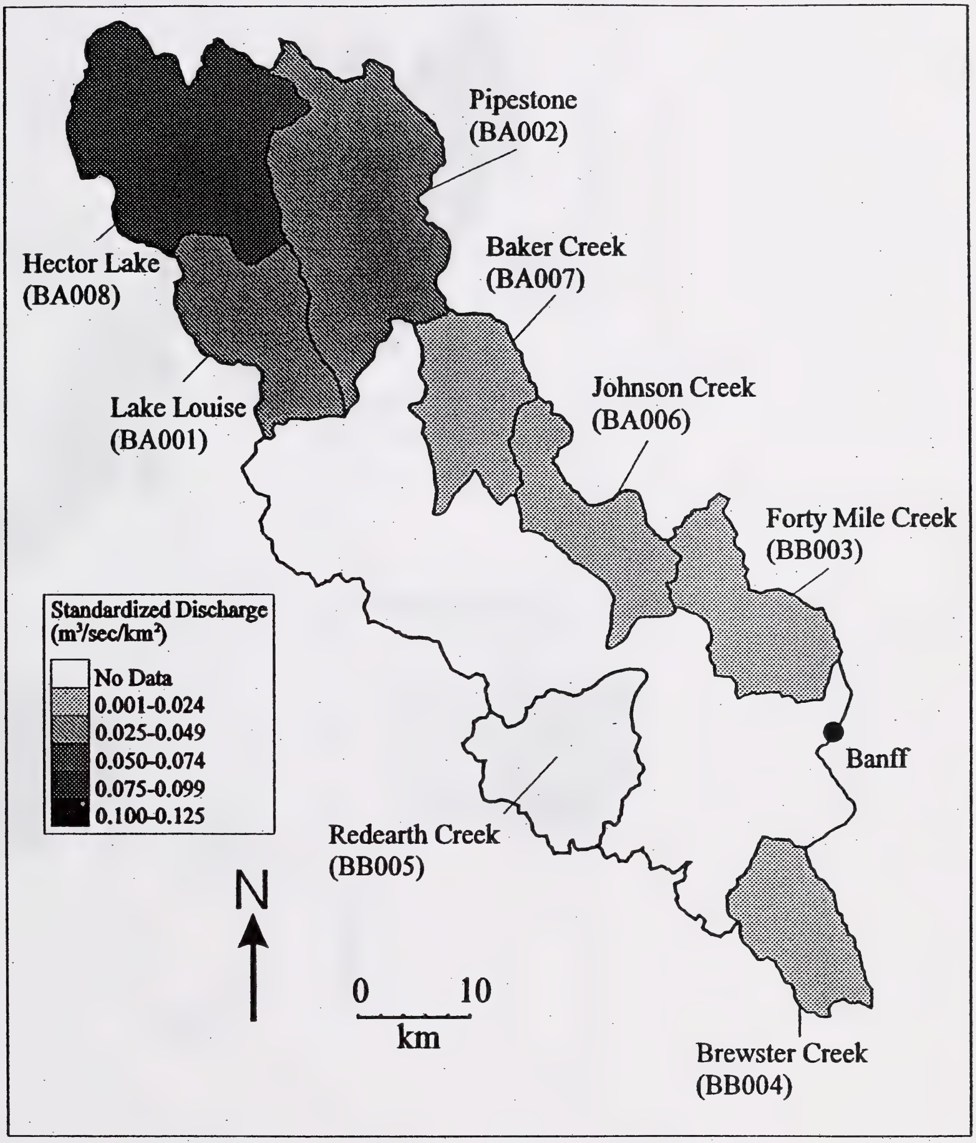

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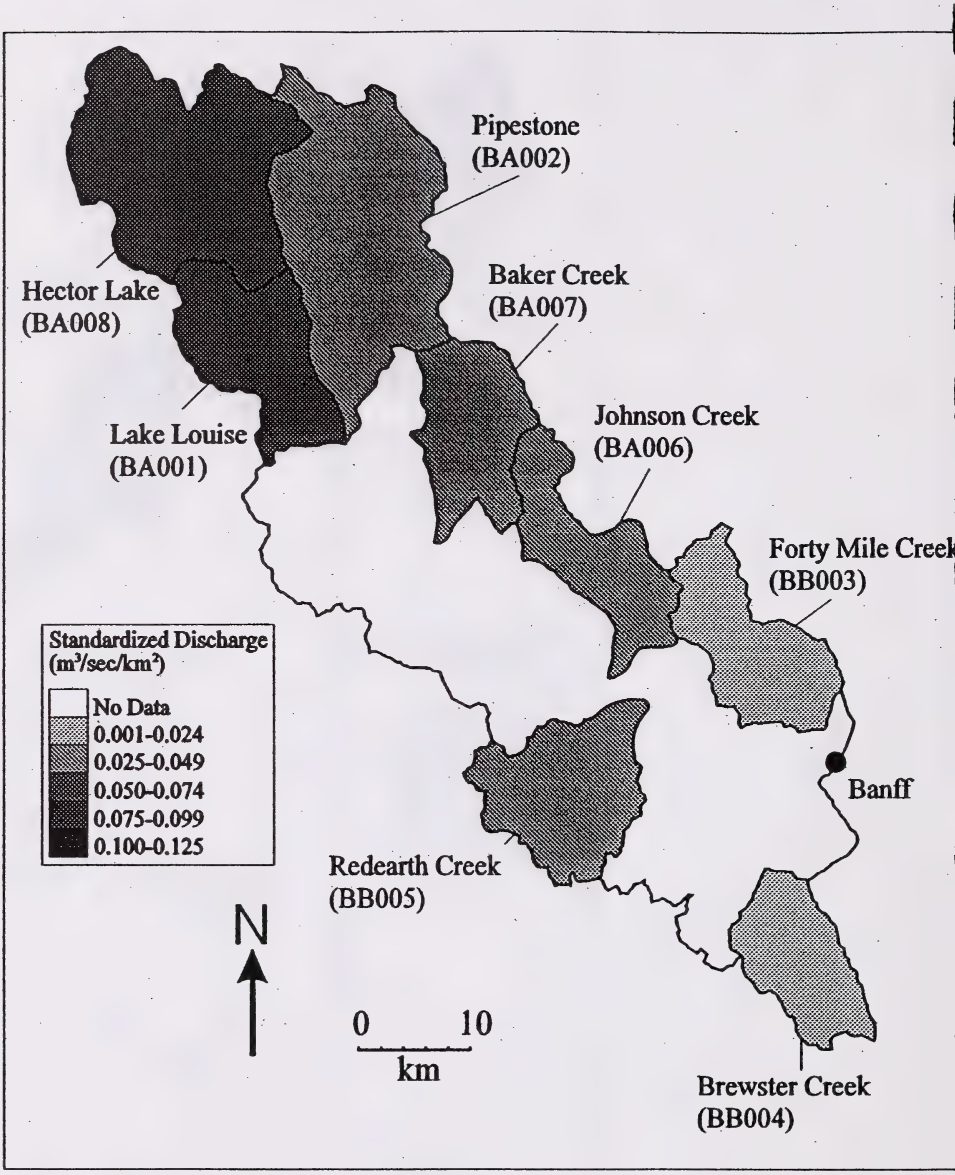

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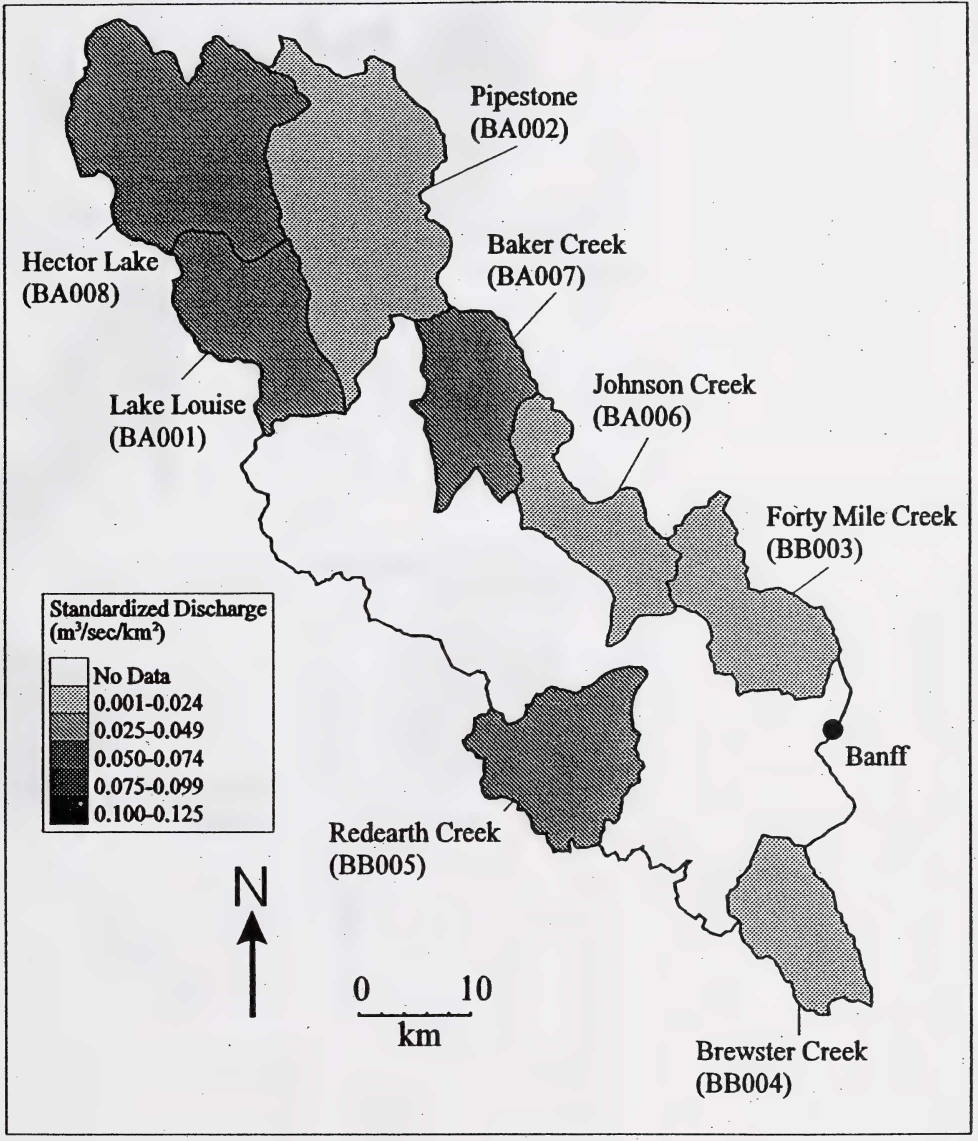

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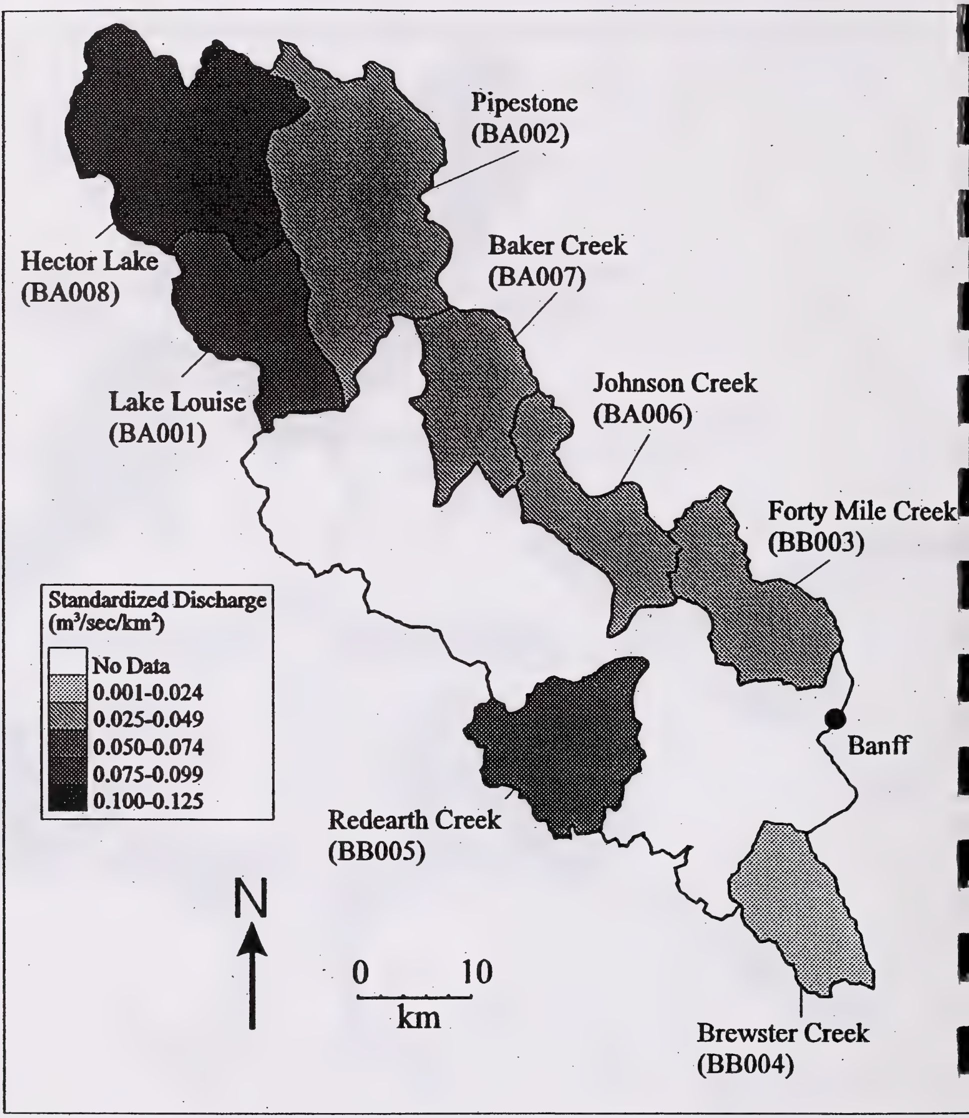

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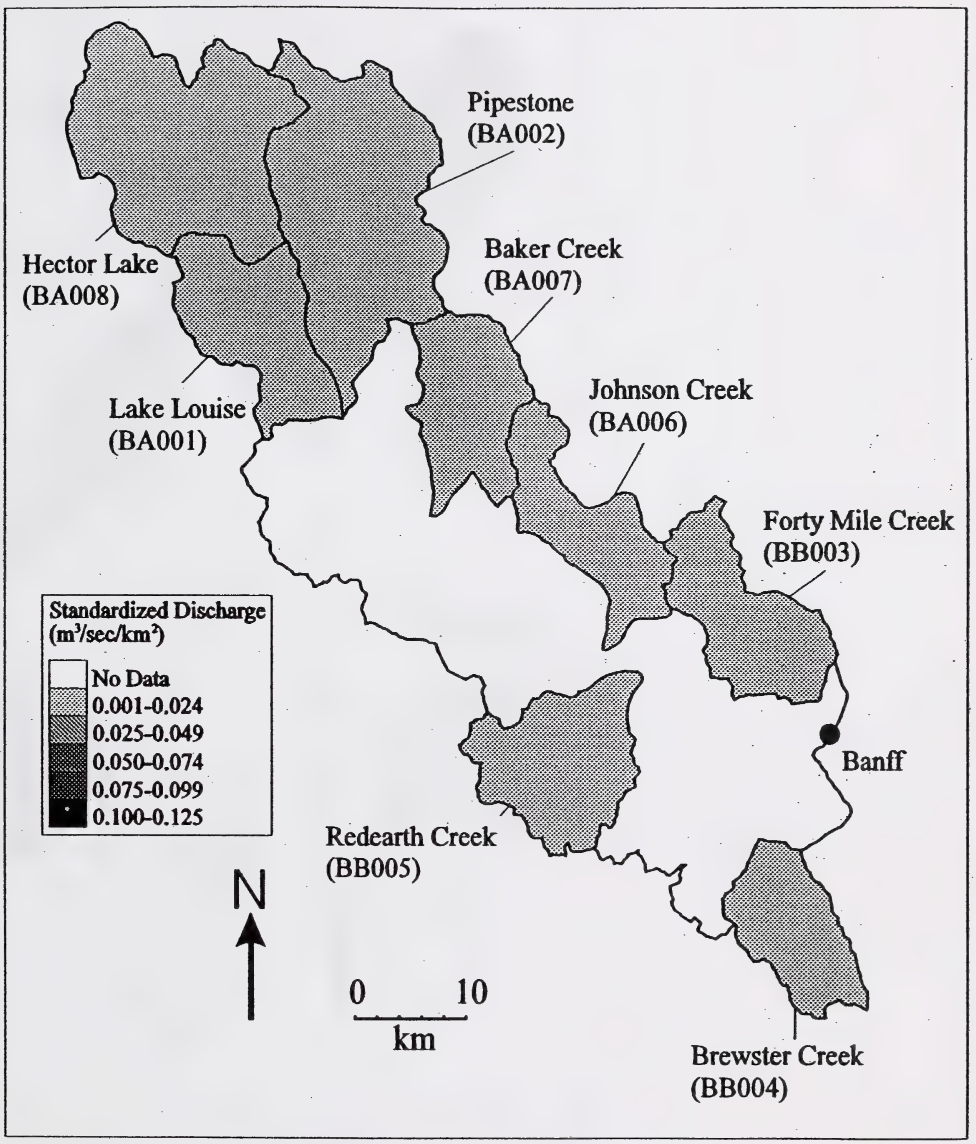

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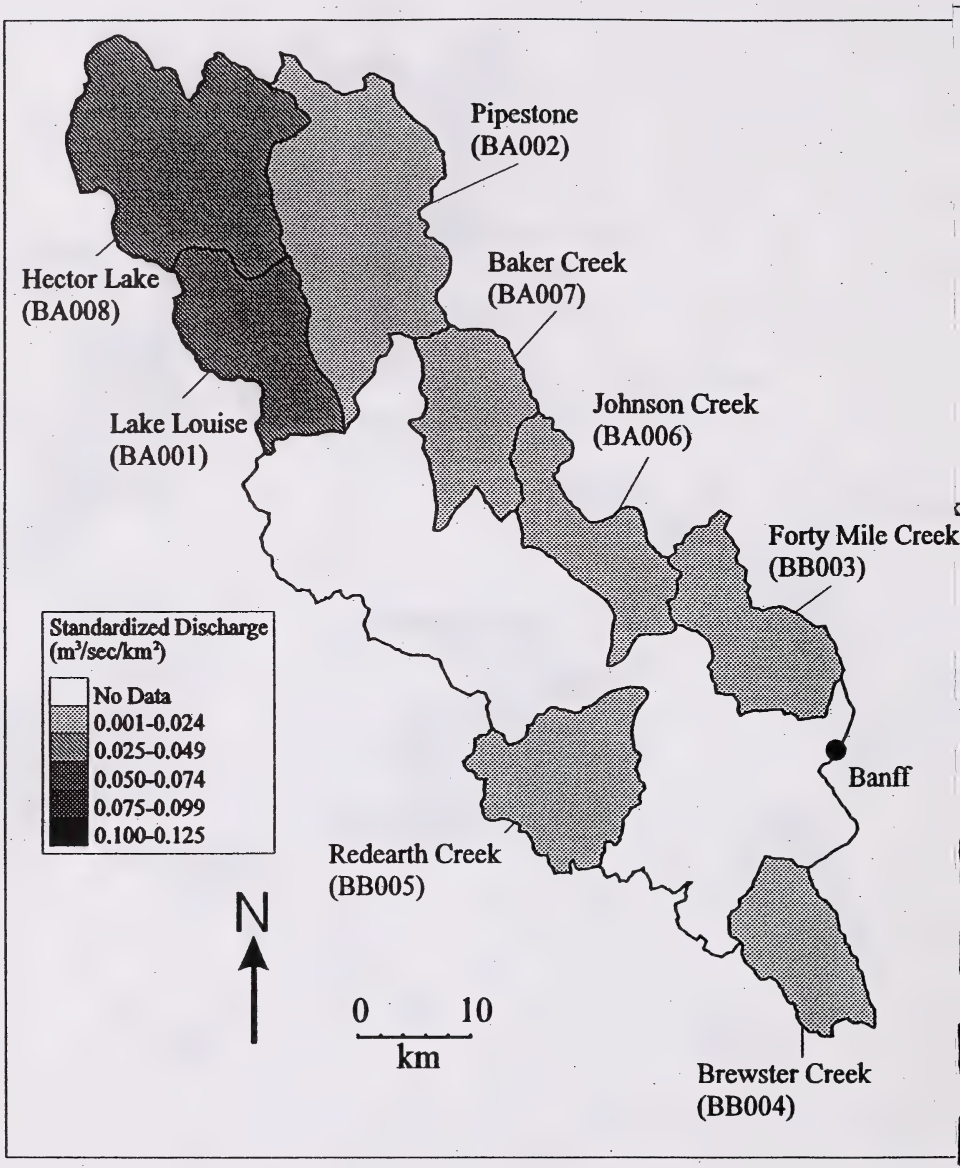

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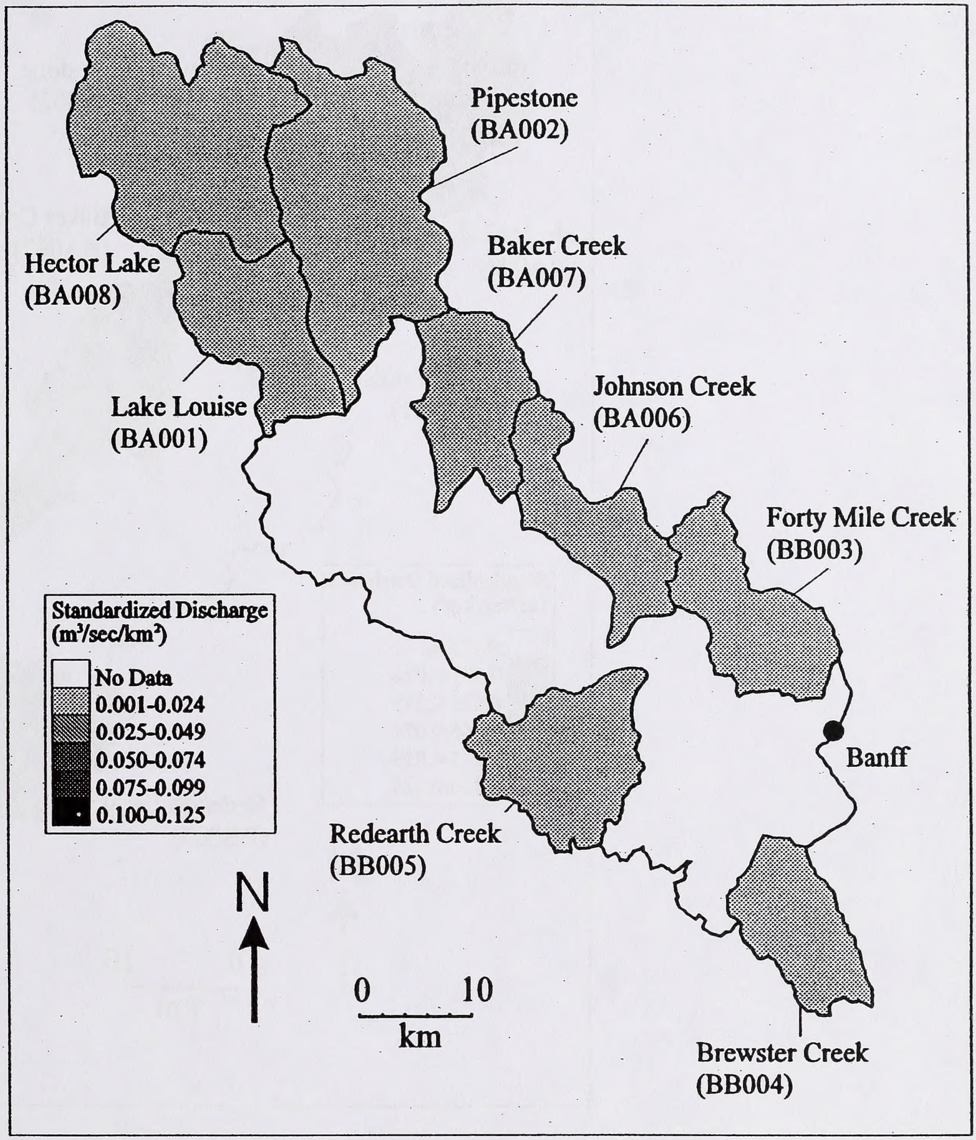

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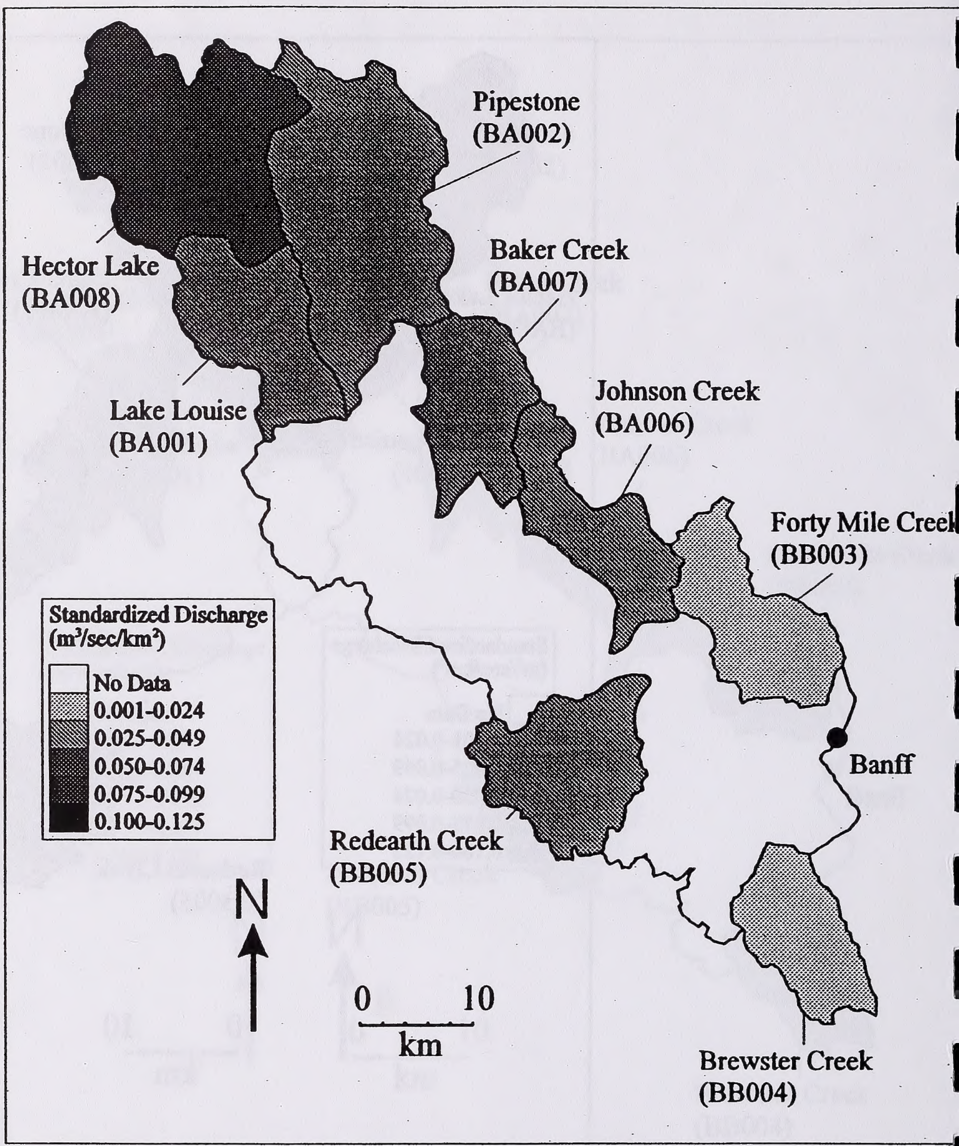

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